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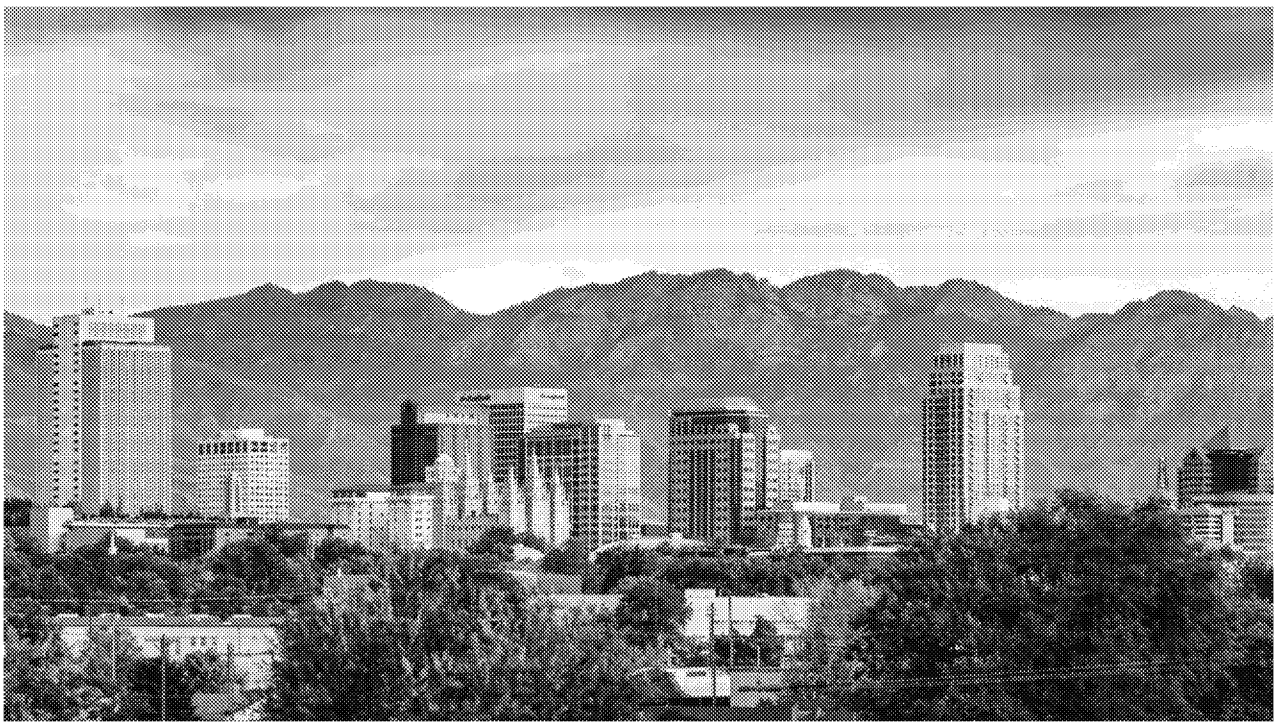
Modeling International Ozone Contribution to Wasatch Front Nonattainment Areas



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EXECUTIVE SUMMARY

The United States Environmental Protection Agency (EPA, 2020a) has designated two areas along the Wasatch Front of Utah as Marginal Nonattainment for the 2015 Ozone National Ambient Air Quality Standard (NAAQS). The monitored "design value" (DV) determines the air quality status of each area. An area violates the 2015 ozone NAAQS when the DV exceeds 70 parts per billion by volume (ppb).

These areas must attain the ozone NAAQS by August 3, 2021 based on ambient air monitoring during 2018-2020. If an area fails to attain, EPA will "bump up" the nonattainment classification from Marginal to Moderate unless the State of Utah requests and receives relief under established provisions of the Clean Air Act. The requirements for Moderate nonattainment areas include the development of a State Implementation Plan (SIP) that specifies new control measures and demonstrates attainment of the ozone NAAQS by August 3, 2024 based on monitoring during 2021-2023. Furthermore, if an area again fails to attain, EPA will reclassify the area to Serious, thereby requiring even more controls.

A study by EPA (2015) shows less than 20% of the ozone in the Wasatch Front results from in-state anthropogenic (human-made) precursor emissions while nearly 60% results from the combination of natural and international anthropogenic emissions. The Utah Division of Air Quality (UDAQ, 2017) reports that less than half of the 20% of ozone from in-state precursor emissions emanate from sources within the State's jurisdiction to control. **Considering extensive precursor controls already implemented to address the fine particulate matter NAAQS, additional controls will be costly and will minimally impact ozone.** In fact, despite a 37% decrease in Wasatch Front precursor emissions over 2005-2017, and related success in improving ambient fine particulate matter, ambient ozone has not responded similarly.

As summarized by EPA (2020c), persistent global circulation patterns establish a direct transport route linking Asia to the western US, which brings pollutant-laden air to North America within days to weeks. Complex topography enhances vertical transport from aloft, and thus high-altitude locations throughout the western US experience the greatest ozone impacts from intercontinental transport. This transport mechanism is especially persistent throughout the summer season.

The Clean Air Act provides an opportunity for nonattainment areas impacted by international contributions to avoid a reclassification to a higher nonattainment level if they fail to attain at current or future nonattainment classifications. According to Section 179B of the Act, the State may develop a technical demonstration showing that the Wasatch Front would attain the ozone standard "but for" the contribution from international emissions.

This study evaluated the potential applicability of the Section 179B provisions for the Wasatch Front Ozone Nonattainment Areas. Specifically, we conducted a preliminary modeling analysis that quantitatively estimated the contribution from global international anthropogenic ozone transport to the Wasatch Front. Ramboll applied two state-of-the-science photochemical models using EPA-derived meteorology and emission datasets representing conditions during 2016 (EPA, 2020b). For one model, we removed international anthropogenic contributions and assessed the resulting ozone contribution at Wasatch Front air quality monitors (a method referred to as sensitivity analysis). For the other model, we tracked the separate emission contributions from Utah, the rest of the US, and international anthropogenic sources to total ozone at Wasatch Front monitors (a method referred to as source apportionment).

Final 179B demonstration guidance developed by EPA (2020c) describes both approaches, and furthermore our methodology followed standardized modeling techniques recommended by EPA (2018) for use in State Implementation Plan (SIP) ozone attainment demonstrations. Following the explicit steps in both of those sets of recommendations, we used modeling results in a relative manner to scale current monitored ozone DVs along the Wasatch Front to estimate what they would be in the hypothetical absence of international transport.

Results from both models show that the Wasatch Front would attain the 70 ppb ozone standard in the absence of international anthropogenic contributions. The current highest DV for the area is 77 ppb, or 6.1 ppb above the 70.9 ppb concentration necessary to attain (by rule the decimal is truncated to 70 ppb). According to the DV scaling technique, modeled international contributions are 8.7 to 12.7 ppb at the most limiting monitoring site (Figure ES-1). Source apportionment results show that the modeled summer-average international contribution at the highest DV site is nearly 10 ppb (Figure ES-2) and is nearly constant throughout the summertime ozone season. Furthermore, these model results are consistent with results previously reported by EPA (2015, 2019) for the same area.

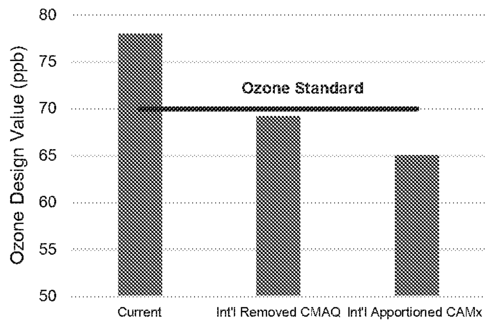

Figure ES-1. Current peak monitored ozone (left) and model-scaled peak ozone without international anthropogenic contributions (middle and right).

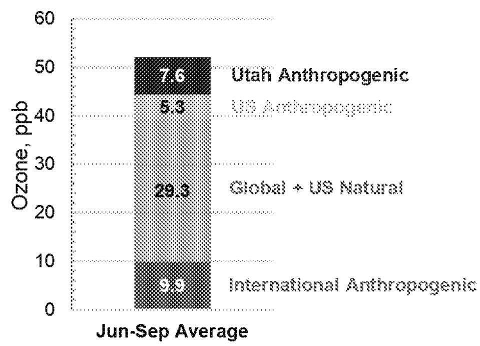

Figure ES-2. Modeled summer-average ozone contributions at the Bountiful Viewmont monitor site.

According to our analysis, both models tend to underpredict on high ozone days at Wasatch Front monitors, most likely from a lack of local ozone production rather than a lack of background ozone entering Utah. This underestimation may lead to a slight overestimate of the international contributions to local DVs, but we estimate that the related error is likely less than 2 ppb. This amount does not change our overall conclusion that the Wasatch Front would attain the standard but for the contribution of international anthropogenic emissions.

This preliminary modeling exercise suggests that Section 179B provisions are applicable for the Wasatch Front Ozone Nonattainment Areas. A more rigorous State-led modeling analysis employing higher resolution and area-specific meteorology and emission inventories is warranted to confirm these results and to support a Section 179B demonstration.

1.0 INTRODUCTION

1.1 Background

The United States Environmental Protection Agency (EPA, 2020a) has designated two areas along the Wasatch Front of Utah as Marginal Nonattainment for the 2015 Ozone National Ambient Air Quality Standard (NAAQS). The Northern Wasatch Front Nonattainment Area includes Salt Lake and Davis Counties and portions of Tooele and Weber Counties. The Southern Wasatch Front Nonattainment Area includes a part of Utah County. The monitored "design value" (DV) determines the air quality status of each area.[1] An area exceeds the 2015 ozone NAAQS when the DV exceeds 70.9 parts per billion by volume (ppb).[2] The 2017-2019 peak DV for the Southern Wasatch Front indicates that the area has attained the ozone NAAQS, while the Northern Wasatch Front has continued to exceed with a peak DV of 77 ppb over the same period.[3]

The federal Clean Air Act sets requirements for States to address nonattainment areas. Requirements for Marginal ozone areas include a comprehensive emission inventory, a Nonattainment New Source Review program, and a Transportation Conformity Demonstration. The Wasatch Front areas must attain the ozone NAAQS by August 3, 2021 based on monitored DVs from 2018-2020. If an area fails to attain, EPA will "bump up" the nonattainment classification from Marginal to Moderate unless the State of Utah requests and receives relief under established provisions of the Clean Air Act (discussed below).

The Clean Air Act requirements for Moderate nonattainment areas are more onerous and include the development of a State Implementation Plan (SIP) that demonstrates attainment of the ozone NAAQS by August 3, 2024 based on DVs from 2021-2023. In addition to the requirements for Marginal areas, the SIP must include reductions in VOC emissions by 15% compared to the 2017 baseline level, Reasonably Available Control Technology for major stationary sources, increased air permit offset ratio for major projects and major modifications, and additional controls as needed to demonstrate attainment. Emission reductions from controls implemented before January 1, 2018 will not count toward the required 15% VOC reduction for Moderate nonattainment areas. Furthermore, if an area again fails to attain, EPA will reclassify the area to Serious, thereby requiring even more controls.

Ozone is not emitted, but rather chemically formed. In the lower atmosphere, ozone forms from precursor emissions that react in the presence of sunlight, including nitrogen oxides (NOx), volatile organic compounds (VOC), methane and carbon monoxide (CO). Natural ozone levels in the lower atmosphere range 10-30 ppb across the globe, while anthropogenic (human-caused) contributions increase the global background to 30-50 ppb, or 40-70% of the NAAQS (Jaffe et al., 2018). Background ozone commonly reaches 60 ppb or more in the elevated intermountain western US because ozone naturally increases with altitude and complex terrain induces deep mixing of mid-tropospheric air to ground level (EPA, 2015).

Based on numerous studies summarized by EPA (2020c), persistent global circulation patterns establish a direct transport route linking Asia to the western US. Rising air currents in low pressure systems over the western Pacific loft pollutant-laden air from eastern Asia into the mid and upper troposphere, which is transported to North America within days to weeks. Ozone can persist at such

[1] For ozone, the EPA defines the DV at each monitoring site as the 3-year average of the annual 4^{th}-high of the maximum daily 8-hour average (MDA8) ambient concentration (40 CFR §50.19).

[2] The ozone NAAQS is defined as 0.070 ppm, where Appendix U to 40 CFR Part 50 (Section 3, paragraph (e)) requires the design value to be reported in ppm with additional digits to the right of the third decimal place truncated.

[3] Based on latest EPA-official 2017-2019 DVs (https://www3.epa.gov/airquality/greenbook/jdtc.html).

altitudes because of low temperatures and relative lack of chemical sinks. Sinking air within high pressure systems over the eastern Pacific brings upper tropospheric air back to the surface over the western US. Complex topography enhances vertical transport from aloft, and thus high-altitude locations throughout the western US experience the greatest ozone impacts from intercontinental transport. This transport mechanism is especially persistent throughout the summer season.

The State's ability to reduce ozone locally is limited because of the amount of ozone generated by local sources over which the State has no control, and contributions from other states, other countries and natural sources. A study by EPA (2015) shows less than 20% of the ozone in the Wasatch Front results from in-state anthropogenic emissions while nearly 60% results from the combination of natural and international anthropogenic emissions (Figure 1). The Utah Division of Air Quality (UDAQ, 2017) reports that of the 20% of ozone generated from Utah VOC and NOx emissions, 65% are attributed to mobile sources over which the State has no control,[4] 30% emit from difficult-to-control area sources,[5] and 15% emit from electric generation and industrial sources. Considering extensive controls already implemented for $PM_{2.5}$ and its precursors (including NOx and VOC) on local stationary sources, additional controls will be costly and will minimally impact ozone. In fact, despite a 37% decrease in Wasatch Front NOx+VOC emissions over 2005-2017, and related success in improving ambient $PM_{2.5}$, ambient ozone has not responded similarly (Figure 2).

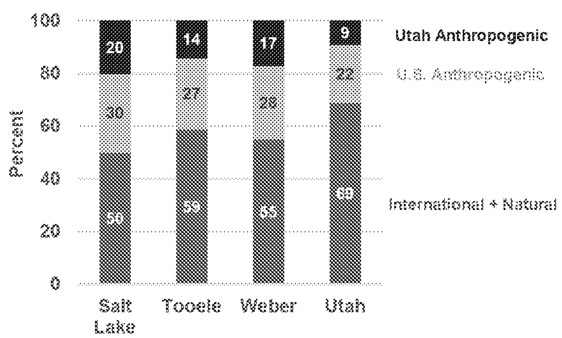

Figure 1. EPA (2015) ozone source apportionment in Wasatch Front Counties, Utah.

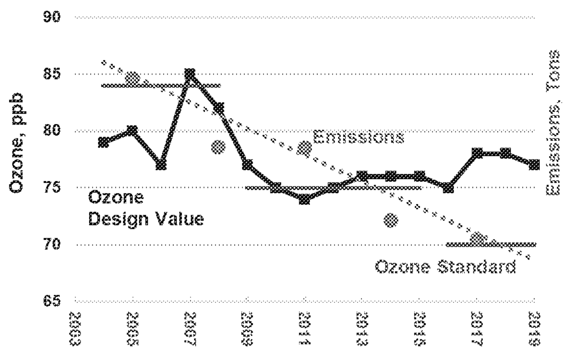

Figure 2. Trends in Wasatch Front NOx+VOC emissions and ozone DV relative to the ozone NAAQS.

The Clean Air Act provides an opportunity for nonattainment areas impacted by international contributions to avoid a reclassification to a higher nonattainment level. According to Section 179B of the Act, the State may develop a technical demonstration showing that the Wasatch Front would attain the ozone standard "but for" the contribution from international emissions. If submitted prior to reclassification to Moderate based on exceeding 2018-2020 DVs, and EPA approves the 179B demonstration that the area ***would have attained the standard*** but for international contributions, the area would remain at Marginal. EPA (2020c) calls this a "retrospective demonstration". If submitted after reclassification to Moderate, and EPA approves the demonstration that the area ***would attain the standard by the next attainment date*** if not for the international contributions, the area would remain at Moderate. EPA (2020c) calls this a "prospective demonstration". In the latter

[4] Mobile sources include both on-road vehicles (cars and trucks) and off-road equipment (agriculture, construction, mining, rail, air, etc.). Utah must rely on emission reductions from motor vehicle fleet turnover.
[5] Area sources include widespread population-based activity such as residential and commercial sources such as gas stations, dry cleaners, restaurants, paint shops, etc.

case, all additional Moderate area SIP requirements would still apply other than a demonstration that the area will attain the NAAQS by the attainment date.

1.2 Objectives of This Study

This study evaluated the potential applicability of the Section 179B provisions for the Wasatch Front Ozone Nonattainment Areas. The analysis followed EPA guidance for 179B demonstrations, adhered to EPA SIP modeling guidelines, and applied EPA modeling datasets to quantitatively estimate the contribution from global international anthropogenic ozone transport along the Wasatch Front.

To meet the study objectives, Ramboll applied two state-of-the-science photochemical models using EPA-derived meteorology and emission datasets representing conditions during 2016 (EPA, 2020b):

1) For one model, we removed international anthropogenic contributions and assessed the resulting ozone contribution at Wasatch Front monitors, a method referred to as sensitivity analysis.

2) For the other model, we tracked the separate emission contributions from Utah, the rest of the US, and international anthropogenic sources to total ozone at Wasatch Front monitors, a method referred to as source apportionment.

Final 179B guidance developed by EPA (2020c) describes both approaches, and furthermore our methodology followed standardized modeling techniques recommended by EPA (2018) for use in ozone SIP attainment demonstrations. The guidance states on page 41, "Chemical Transport Modeling (CTM) is the preferred approach for quantifying international contribution for pollutants with a secondary component (such as O_3 and $PM_{2.5}$, which are formed, at least in part, as a result of photochemical reactions of precursor gases in the atmosphere."

Adhering to the explicit steps in those recommendations, we applied model results in a relative manner to estimate how current monitored ozone DVs in the Wasatch Front would change in the hypothetical absence of international transport.

Section 2 describes the modeling systems employed in this study and procedures to assess model-predicted international contributions. Section 3 summarizes model performance in replicating measured ozone levels at Wasatch Front monitors during the summer of 2016 from which to establish a level of confidence in model outcomes. Section 4 presents modeling results from the two approaches, and Section 5 presents our conclusions.

2.0 MODELING SYSTEM AND APPROACH

2.1 Modeling System

This study employed the EPA (2020b) 2016 national Modeling Platform (MP), which provides emissions, meteorology, and boundary condition inputs for two state-of-the-science photochemical grid models: the Community Multiscale Air Quality (CMAQ; EPA, 2020d) and the Comprehensive Air quality Model with extensions (CAMx; Ramboll, 2020). These inputs allow for a full calendar-year (2016) simulation of air quality over the US. The temporal resolution is hourly and the grid resolution over the conterminous US (CONUS) domain is 12 km (Figure 3).

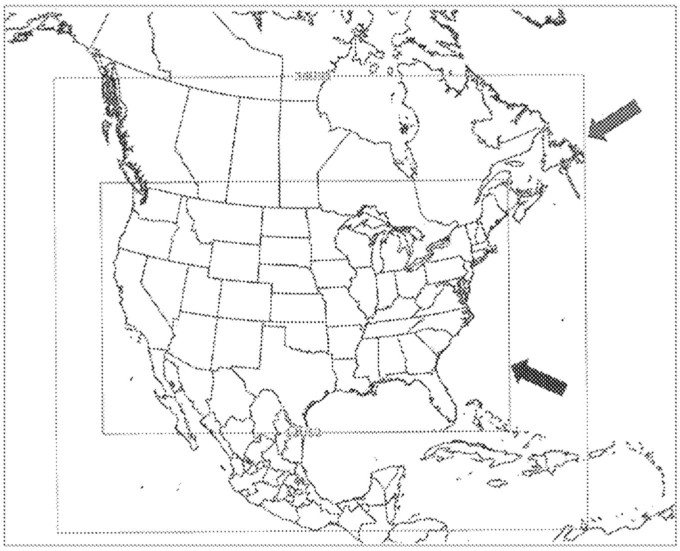

Figure 3. Depiction of the EPA 2016 MP modeling domains: the outer domain (green) covers most of North America with 36 km grid spacing; the inner domain (red) covers the US at 12 km grid spacing. Applications described in this report were run on the inner grid.

EPA developed several MP versions since 2018: the initial version is called "Beta" while the current version is called "V1". These versions are primarily related to North American emission updates; see EPA (2020b) for detailed information on data sources for US, Canadian, and Mexican anthropogenic precursor emissions, and the process to estimate natural precursor emissions (biogenic, lightning NOx, fires, oceanic).

EPA developed meteorological fields (winds, temperature, pressure, humidity, clouds/precipitation, turbulence parameters, etc.) using the Weather Research and Forecasting Model (WRF; NCAR, 2020).

EPA derived boundary conditions (i.e., space/time-varying characterization of pollutant inflow) for the North American domain from a previous CMAQ application over the entire northern hemisphere using anthropogenic and natural global emissions generated from several international inventories and models. EPA ran the hemispheric CMAQ for two scenarios:

1) a "Base" case that includes emissions from all sources and activities representative of 2016

2) a "Zero Rest of World" (ZROW) case that excludes all non-US anthropogenic emissions, leaving only US and global natural emissions.

North American boundary conditions were prepared for both scenarios.

In 2019, EPA used both sets of boundary conditions with the CMAQ Beta MP to run the BASE and ZROW scenarios on the finer-scale US domain but ran only the CAMx Beta MP for the BASE scenario. Additionally, EPA conducted a general model performance evaluation for the CMAQ and CAMx BASE scenarios that included statistical and graphical comparisons of simulated ozone against monitored ozone across the US.[6] We analyzed these products with a focus on the Wasatch Front, as described in Section 3.

2.2 Modeling International Ozone Contributions

Our approach applied two key methodologies, sensitivity analysis and source apportionment, recommended by EPA's (2020c) 179B guidance document for ozone assessments, as well as by EPA's (2018) photochemical modeling guidance for SIPs. This helped to establish a plausible range of international anthropogenic emission (IAE) contributions in the Wasatch area and to provide a weight of evidence.

The sensitivity analysis quantified how simulated concentration patterns respond to changes in certain input parameters. As described above, EPA had previously performed the necessary modeling for this type of assessment. We obtained EPA's CMAQ Beta MP output files for their BASE and ZROW scenarios, which contained gridded (12 km resolution over the US) MDA8 ozone concentrations for every day of 2016. The ZROW case represents the ozone pattern resulting from direct removal of IAE contributions, and the difference between the BASE and ZROW scenarios each day and at each grid cell represents the pattern of ozone response from removing IAE. We extracted these ozone data for the June-August summer ozone season from the portion of the modeling grid that covers the Wasatch Front nonattainment areas.

The source apportionment methodology quantified how simulated total concentrations are apportioned into contributions from different source regions and/or sectors. Apportionment is identical to sensitivity differencing when concentrations result from linear processes (e.g., dust or other inert PM), but can differ substantially when concentrations result from non-linear processes (e.g., ozone chemistry). In the latter case, apportionment changes when the chemical environment is altered, such as modeling a different emission scenario. As the model runs, source apportionment internally tracks contributions from emissions, dispersion, chemistry, and removal among the targeted source regions/sectors.

Preexisting modeling results for this method were not readily available, so we ran CAMx with its Ozone Source Apportionment Technology (OSAT). We applied CAMx/OSAT for the BASE scenario over the June-September 2016 ozone season using the EPA V1 MP, and tracked three source regions (Utah, other US, and non-US) and two sectors (anthropogenic and natural). Non-US emissions included anthropogenic and natural sources within the North American CAMx domain (Canada, Mexico and oceanic sources outside a 200 km coastal zone) and from outside the modeling domain (via BASE and ZROW boundary conditions).

It was important to quantify the ability of both CMAQ (Beta MP) and CAMx (V1 MP) to sufficiently replicate historical 2016 ozone patterns in space and time relative to monitored ozone data along the Wasatch Front. Good performance helps establish trust that the model is correctly characterizing chemical and physical processes and responds correctly to input modifications. In particular, the

[6] The products from the performance evaluation are distributed by the Lake Michigan Air Directors Consortium (LADCo, 2020).

complex topography of the area influences meteorology and air quality patterns, presenting challenges to any air quality modeling exercise. In this case, the 12 km grid resolution of the EPA's national MP does not adequately resolve the local terrain features, nor details in urban vs. rural (biogenic) emission distributions, adding to model uncertainty with respect to the mix of local vs. regional ozone production and transport. Furthermore, while EPA develops the best possible nationwide information at each iteration of the MP, EPA does not spend the considerable time necessary to fine-tune model inputs and treatments by which to optimize model performance in all areas of the US. Our Wasatch-specific model performance evaluation is detailed in Section 3.

2.3 Assessing Contributions to Ozone DVs

We followed EPA (2018) modeling guidance for SIP demonstrations to assess the contribution of IAE on local Wasatch Front monitored DVs. The approach involved scaling the DV at each monitoring site by the relative modeled change in ozone between the baseline and scenario cases. This process is codified in EPA's Software for the Modeled Attainment Test – Community Edition (SMAT-CE) software (EPA, 2020e). The software allows use of year-specific modeling to apply to a range of recent DV years. The specific approach in this analysis is summarized below.

We started with the EPA's 2016 CMAQ Beta MP output files from their BASE and ZROW scenarios, which contain gridded maximum daily 8-hour average (MDA8) ozone concentrations over the entire US domain. We supplied gridded MDA8 ozone concentrations over June-August to SMAT-CE and the software identified the grid cells containing Wasatch Front monitor locations. At each site, the program averaged modeled MDA8 ozone concentration over at least 10 days exceeding 60 ppb for use in the DV scaling function.

SMAT-CE calculates a site-specific "relative response factor" (RRF), which is the ratio of average MDA8 ozone in the ZROW case ($\bar{C}_{ZROW}$) to the average MDA8 in the BASE case ($\bar{C}_{Base}$) over the modeled high ozone days. The program then applies the RRF to the selected DV to yield the adjusted DV for the ZROW scenario. This is shown mathematically below:

$$DV_{scaled} = DV_{monitored} \times \underbrace{\left(\frac{\bar{C}_{ZROW}}{\bar{C}_{Base}}\right)}_{\text{RRF}}$$

Model-scaled DVs less than or equal to 70.9 ppb indicate attaining monitors "but for" the contribution from IAE.

We followed a similar approach for CAMx OSAT results. For the RRF numerator, we supplied the tagged MDA8 ozone concentrations representing ozone from all sources except the apportioned IAE component, averaged over at least the top 10 days exceeding 60 ppb in total ozone over June-September. For the RRF denominator, we supplied the average total MDA8 ozone (all sources inclusive of IAE) over those same days.

3.0 MODEL PERFORMANCE EVALUATION

3.1 CMAQ Beta MP Ozone

We evaluated CMAQ-predicted MDA8 ozone at each of the 9 Wasatch Front monitoring sites operating during June-August 2016 (Figure 4). Appendix A provides time series of MDA8 ozone and Table 1 presents summer-average statistical results against observed MDA8 values over all sites (LADCo, 2020).

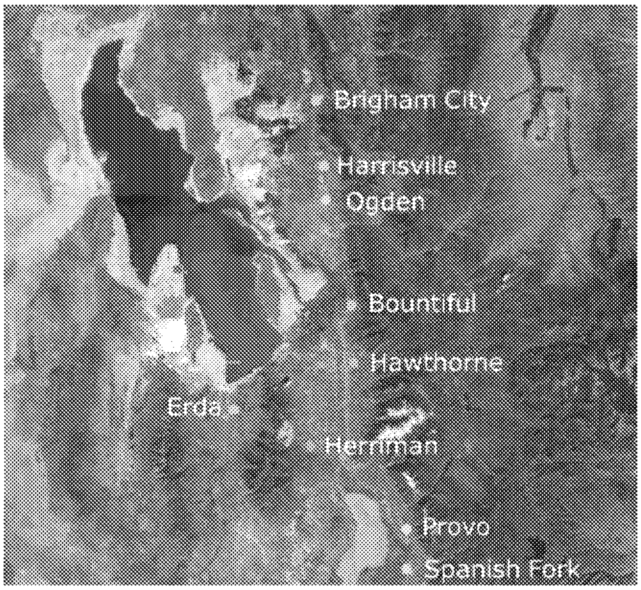

Figure 4. Satellite map view of the Wasatch Front and locations of monitoring sites supporting the model performance evaluation.

Table 1. CMAQ Beta MP model performance statistics for MDA8 ozone over 9 Wasatch Front monitoring sites during June-August 2016. Correlation refers to the linear correlation coefficient (R), bias refers to normalized mean bias (signed error), and error refers to normalized mean error (unsigned error). Values shown in green meet performance criteria benchmarks suggested by Emery et al. (2016).

	Correlation (R)	Bias	Error
All days June-August	0.63	-7%	11%
Observed Days > 60 ppb	0.34	-13%	14%
Criteria benchmark	>0.50	<±15%	<25%

Table 1 shows that CMAQ adequately replicates 2016 summertime MDA8 ozone throughout the Wasatch Front with statistical results within criteria benchmarks (Emery et al., 2016). This means that model bias, unsigned error, and correlation coefficient are consistent with photochemical model performance levels historically achieved throughout the US, and typical of western US applications. Model performance degrades on days when observed MDA8 exceeded 60 ppb, with consistent underpredictions. On these days, correlation is significantly lower and outside benchmarks, which means there is less systematic model-measurement agreement (i.e., more random effects) in day-to-day variability. This is partly because of fewer model-observation pairs on this subset of days.

The underprediction on high ozone days adds uncertainty to the IAE contribution assessment since the DV scaling calculation focuses on the high days. The specific source of the underprediction can influence the DV scaling analysis, as demonstrated in Table 2 and described in the following hypothetical examples:

- If the cause of bias is spread equivalently across all sources, this is the type of broad systematic error that the RRF approach is designed to mitigate since only relative model changes are applied (i.e., applying a ratio of two runs reflecting the same bias effectively cancels the systematic bias). However, one still needs to be concerned with the influence of compensating over/underprediction biases among model processes in such cases.
- If the primary cause for underprediction is related solely to the IAE contribution (all else being well-predicted), then the IAE contribution would be too small, the RRF would be too large when IAE is removed in the ZROW case, and the DV projections would be too high (not enough IAE contribution is removed).
- If the primary cause for underprediction is related solely to the local/regional contribution (all else being well-predicted), then the IAE contribution would be too large relative to the local/regional contributions, the RRF would be too small when IAE is removed in the ZROW case, and the DV projections would be too low (too much relative IAE contribution is removed).

Table 2. Hypothetical examples of how a model scaled DV changes for different scenarios of model performance: (1) perfect model; (2) both IAE and local/regional contributions are equivalently biased low; (3) IAE is biased low while local/regional contributions are perfect; and (4) local/regional are biased low while IAE is perfect.

	Contributions			Base DV = 77 ppb	
	IAE	**Local/Regional**	**Total**	**RRF**	**Scaled DV**
1) Perfect Model	7.0	70.0	77.0	0.909	70.0
2) All low -15%	6.0	59.5	65.5	0.909	70.0
3) IAE low -15%	6.0	70.0	76.0	0.922	71.0
4) Local/Regional low -15%	7.0	59.5	66.5	0.895	68.9

To assess which of the causes for underprediction might be occurring, we analyzed CMAQ results at a single EPA high-altitude monitoring site called "Gothic" in the Colorado Rockies. Set at an altitude of approximately 3000 m (10,000 ft), this is the closest site to the Wasatch Front that consistently measures mid-tropospheric air. Its remote location results in little influence from local urban areas and so it provides an indication of higher-elevation, regional and global-scale ozone concentrations over the western US.

Figure 5 shows a time series of CMAQ predicted MDA8 ozone against Gothic observations during the summer of 2016. CMAQ exhibits very good agreement with measurements, suggesting that US background and US regional ozone levels are well simulated. This suggests that local ozone production may be the primary cause for underpredictions on high ozone days in the Wasatch Front, which is further supported in our evaluation of CAMx in the next sub-section. Thus, scaled DV projections may be too low (too much relative IAE contribution is removed) like in example (4) in Table 2. From the examples in Table 2, which apply a conservative bias of 15% compared to 7-13% bias reported in Table 1, the estimated error in the scaled DV is likely constrained within 1-2 ppb (compare the scaled DV in example (4) to examples (2) and (3)).

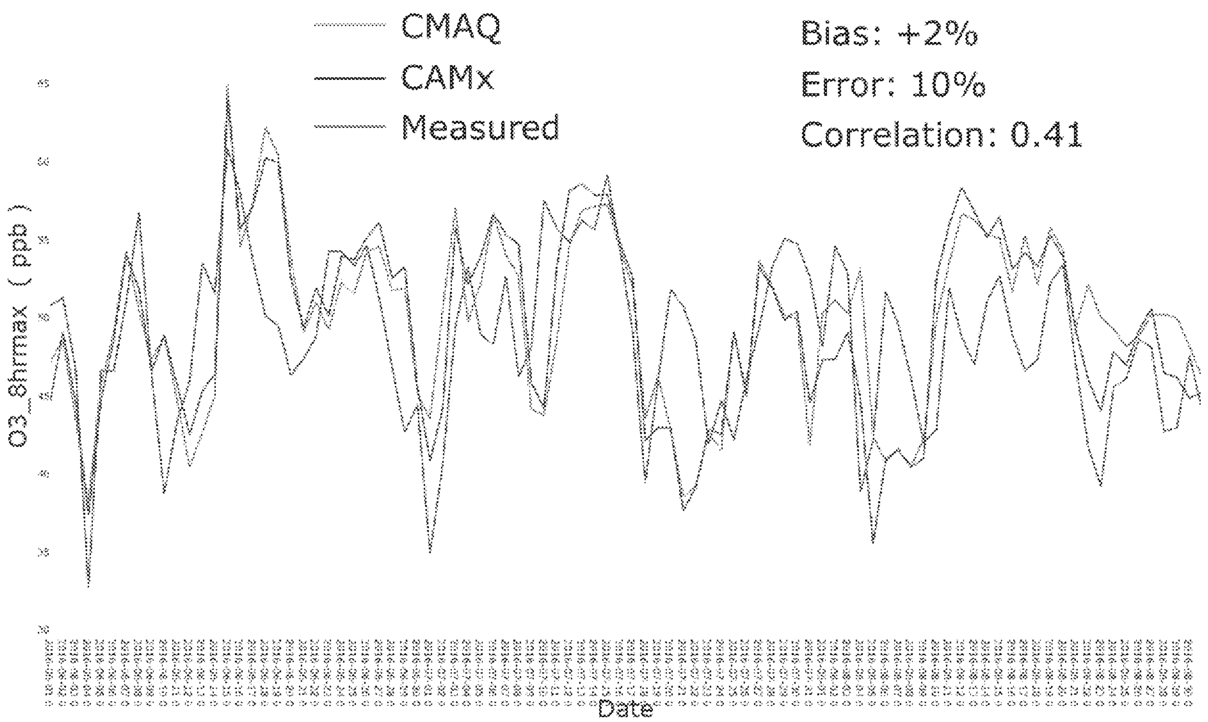

Figure 5. Time series of monitored and predicted MDA8 ozone at the Gothic, Colorado monitoring site. Predictions are taken from EPA Beta MP CMAQ and CAMx simulations (LADCo, 2020).

Balloon-borne ozonesondes are another source of upper-air ozone data; the closest launch site is Boulder, Colorado. While they provide very good vertical resolution of the ozone profile well into the stratosphere, Boulder ozonesondes are launched infrequently and concentrations in the lowest few km are influenced by emissions from Denver and along the Colorado Front Range. We therefore did not include comparisons to ozonesondes in this preliminary modeling analysis.

3.2 CAMx V1 MP Ozone

We evaluated predicted MDA8 ozone from our CAMx V1 MP BASE simulation at each of the same 9 Wasatch Front monitoring sites over the June-September 2016 period. Appendix B provides time series of MDA8 ozone and Table 3 presents summer-average statistical results against observed MDA8 values over all sites. CAMx performance is consistent with and just slightly better than CMAQ, including degraded performance on days when observed ozone exceeded 60 ppb. From the analysis of time series in Appendix B, it is apparent that CAMx performs quite well during September. EPA's CMAQ performance evaluation does not include September, which may be the primary reason for the slightly better statistical values in Table 3.

We further analyzed CAMx performance at the Gothic monitor as well as across the entire inter-mountain western US. Figure 6 displays normalized mean bias for MDA8 ozone at each monitoring site in the region as colored dots, where warm colors (yellow to red) indicate overpredictions and cool colors (green to purple) indicate underpredictions. When considering all days of June-September, bias remains within 10% (well within criteria benchmarks) throughout the region, at both high elevation sites and most sites along the Wasatch Front. Considering only high ozone days greater than 60 ppb, however, Figure 6 reveals more areas of negative bias (underprediction tendency)

Table 3. CAMx V1 MP model performance statistics for MDA8 ozone over 9 Wasatch Front monitoring sites during June-September 2016. Correlation refers to the linear correlation coefficient (R), bias refers to normalized mean bias (signed error), and error refers to normalized mean error (unsigned error). Values shown in green meet performance criteria benchmarks submitted by Emery et al. (2016).

	Correlation (R)	Bias	Error
All days June-August	0.78	-6%	10%
Observed Days > 60 ppb	0.42	-12%	13%
Criteria benchmark	>0.50	<±15%	<25%

scattered across the region, but particularly for all Wasatch Front sites. Note that bias at high altitude sites throughout the Rockies, including Gothic, remains within 10%. This pattern suggests that local ozone production in the Wasatch Front area is indeed underpredicted.

Figure 7 shows time series of CAMx-predicted MDA8 ozone against Gothic measurements. Like CMAQ, the replication of ozone at this isolated high-altitude site is quite good, and even indicates some tendency for overprediction during a few episodes in mid-summer. In fact, bias and error improve during periods when observed MDA8 ozone exceeds 50 ppb. Note again that correlation degrades for this subset of days, but again we attribute that effect mostly to the smaller number of prediction-observation pairs and thus a higher probability of unsystematic (random) error. As seen from the CMAQ evaluation, rather good replication of regional and background ozone throughout the western US, coupled with underestimates of local ozone production in the Wasatch Front, suggest that DV projections from removing the IAE contribution may be too low (too much relative IAE contribution is removed). Based on the conservative analysis described in Table 2, these results continue to indicate that error in the scaled DV is likely constrained within 1-2 ppb.

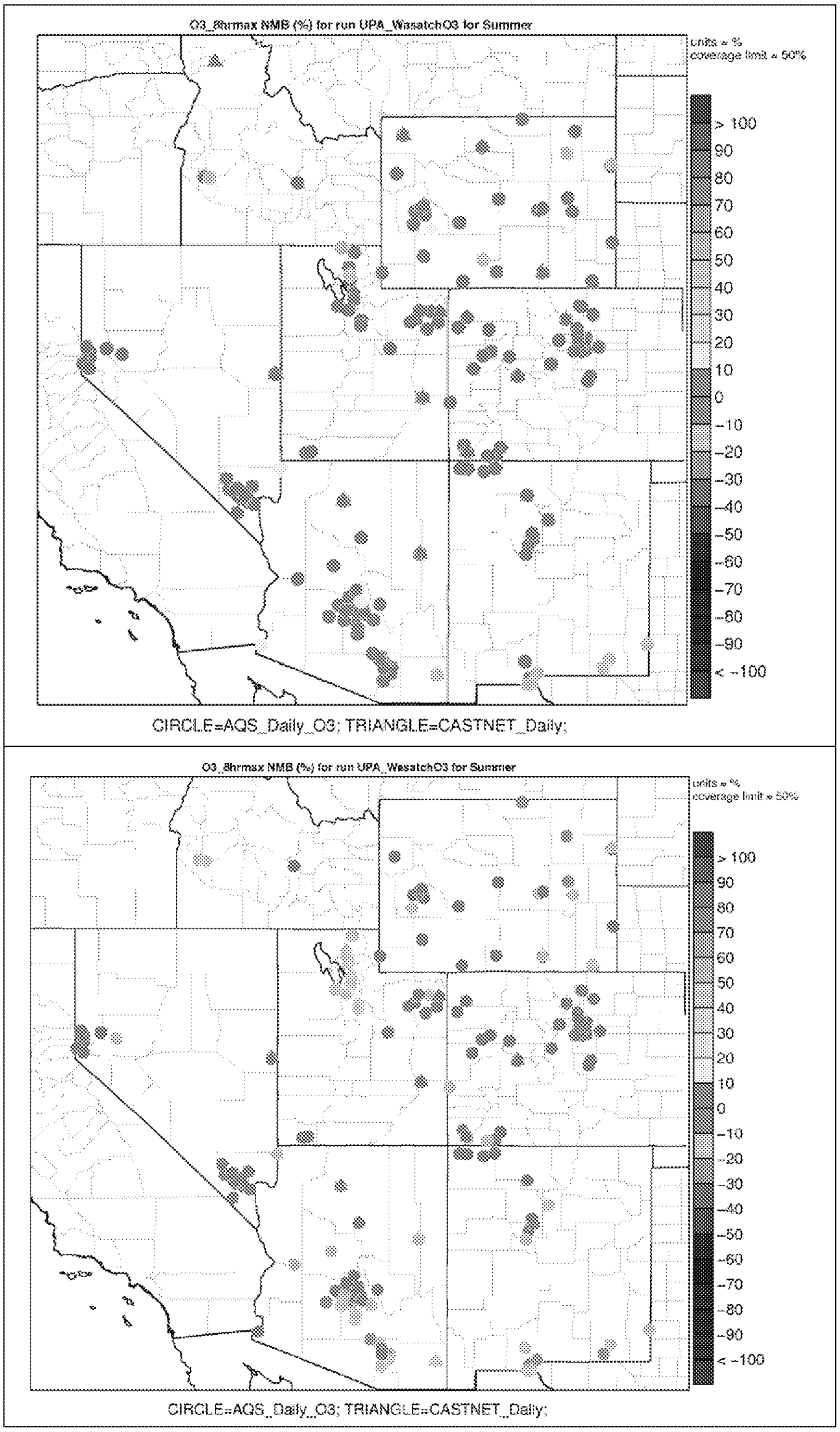

Figure 6. Plots of normalized mean bias (NMB, %) for MDA8 ozone at monitoring sites in the western US. (Top) All days of June-September 2016; (bottom) days at each site when observed MDA8 exceeded 60 ppb. Data from two monitoring networks are shown (AQS and CASTNET).

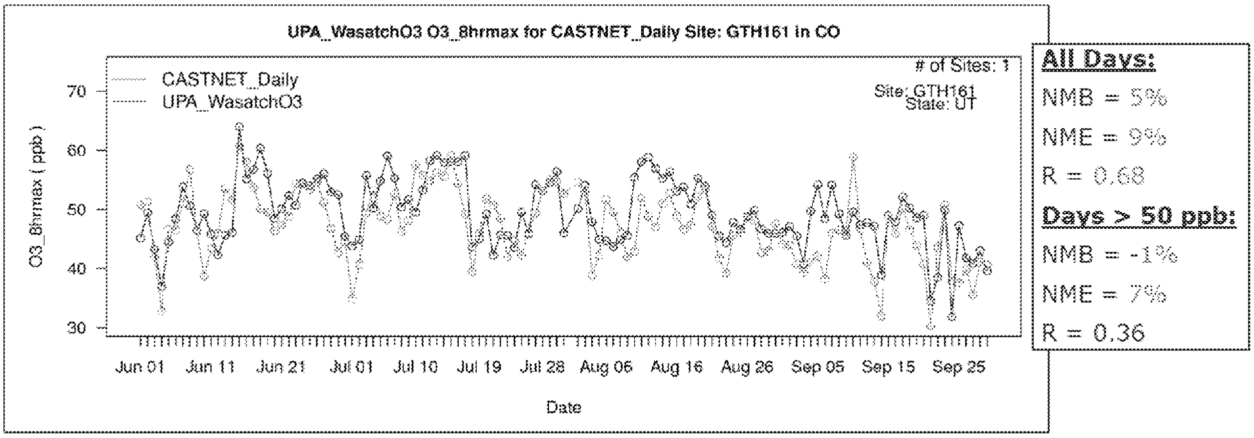

Figure 7. Time series of monitored and CAMx-predicted MDA8 ozone at the Gothic, Colorado monitoring site. Key statistical performance measures are listed on the right for different sets of monitoring days. Green values indicate results that are within statistical criteria benchmarks. NMB refers to normalized mean bias (signed error), NME refers to normalized mean error (unsigned error), and R represents the linear correlation coefficient.

4.0 INTERNATIONAL CONTRIBUTION RESULTS

4.1 Estimates from the EPA CMAQ Beta MP BASE and ZROW Simulations

As described in Section 2.3, we used the EPA's SMAT-CE software to scale DVs at each monitoring site by the relative modeled change in average MDA8 ozone greater than 60 ppb between the 2016 CMAQ Beta MP BASE and ZROW scenarios. We considered only the period of June-August, consistent with EPA's CMAQ BASE model performance evaluation. Model-scaled DVs less than or equal to 70.9 ppb indicate attaining monitors "but for" the contribution from IAE.

Results are shown in Table 4 for modeled RRFs applied to the most recent official 3-year ozone DV period: 2017-2019. At all sites, the CMAQ Beta MP results show that DVs at each site are well below 70 ppb when IAE contributions are removed in the ZROW scenario. Note that the 2017-2019 DV for the single site in the Southern Wasatch Front nonattainment area was already attaining at 70 ppb. We also applied these RRFs to several other DV periods back to 2013 (Appendix C). In all cases the removal of IAE contributions result in DVs well below the 70 ppb standard, with a peak RRF-scaled DV of 69.6 ppb over all of the previous periods. For the 2017-2019 DV period, the peak RRF-scaled DV of 68.3 allows an ample margin for the slight IAE ozone overprediction of up to 2 ppb.

Table 4. Ozone DV scaling results at each Wasatch Front monitoring site using the SMAT-CE tool, based on simulated ozone over June-August 2016 from the EPA CMAQ Beta MP BASE and ZROW results. In every case ZROW results in DV<70 ppb (green), well within attainment.

Site	County	2017-2019 DV[1]	Modeled RRF (ZROW/Base)	ZROW DV (≤70.9 Attains)
Northern Wasatch Front				
490110004 Bountiful	Davis	77	0.8869	68.3
490353006 Hawthorne	Salt Lake	76	0.8924	67.8
490353013 Herriman	Salt Lake	75	0.8686	65.1
490450004 Erda	Tooele	72	0.8592	61.9
490570002 Ogden	Weber	71	0.8811	62.6
490571003 Harrisville	Weber	71	0.8784	62.4
Southern Wasatch Front				
490490002 Provo	Utah	N/A	0.8881	N/A
490495010 Spanish Fork	Utah	70	0.8905	62.3

[1] Based on latest EPA-official 2017-2019 DVs (https://www3.epa.gov/airquality/greenbook/jdtc.html). Data collection at Provo ended prior to 2019 but DVs at that site never exceed 72 ppb going back to 2013.

4.2 Estimates from the CAMx V1 MP OSAT Simulations

We followed a similar approach, as explained in Section 2.3, for CAMx OSAT results. Results are shown in Table 5 for modeled RRFs applied to the most recent official 3-year ozone DV period: 2017-2019. At all sites, the CAMx V1 MP OSAT results show that DVs at each site are even lower than the CMAQ ZROW scenario, and this holds for all other DV periods back to 2013 (Appendix D). In all cases the removal of apportioned IAE contributions result in DVs well below the 70 ppb standard, with a peak RRF-scaled DV of 65.1 ppb over all of the previous periods, again allowing ample margin for the slight IAE ozone overprediction of up to 2 ppb.

Table 5. Ozone DV scaling results at each Wasatch Front monitoring site using the SMAT-CE tool, based on simulated ozone over June-September 2016 from the CAMx V1 MP OSAT results. In every case ZROW results in DV<70 ppb (green), well within attainment.

Site	County	2017-2019 DV[1]	Modeled RRF	OSAT DV (≤70.9 Attains)
Northern Wasatch Front				
490110004 Bountiful	Davis	77	0.8346	64.3
490353006 Hawthorne	Salt Lake	76	0.8293	63.0
490353013 Herriman	Salt Lake	75	0.8224	61.7
490450004 Erda	Tooele	72	0.8375	60.3
490570002 Ogden	Weber	71	0.8297	58.9
490571003 Harrisville	Weber	71	0.8432	59.9
Southern Wasatch Front				
490490002 Provo	Utah	N/A	0.8326	N/A
490495010 Spanish Fork	Utah	70	0.8330	58.3

[1] Based on latest EPA-official 2017-2019 DVs (https://www3.epa.gov/airquality/greenbook/jdtc.html). Data collection at Provo ended prior to 2019 but DVs at that site never exceed 72 ppb going back to 2013.

Figure 8 presents ozone source apportionment results over the June-September 2016 period at the most limiting (highest) DV site in the Northern Wasatch Front nonattainment area, Bountiful Viewmont. The left side of the figure shows a time series of MDA8 ozone, stratified by the OSAT-tracked contributions. The sum of all individual contributions results in the total MDA8 ozone simulated by CAMx, as shown at the top of the grey area. The right side of the figure shows the June-September average MDA8 ozone contributions, which sum to a total average ozone concentration of about 52 ppb.

OSAT estimates that on average, roughly 58% of MDA8 ozone (30 ppb of 52 ppb) at Bountiful Viewmont is derived from natural emissions globally (including local and US biogenic sources) and a minor amount from US anthropogenic sources that recirculated around the globe back to the Wasatch Front (we did not separately track the small US recirculation portion). Anthropogenic emissions within Utah and the rest of the US contribute on average 10% and 15% of total ozone, respectively. The natural (green), Utah (grey) and US (yellow) contribution estimates vary substantially throughout the summer of 2016. In contrast, IAE contributions (orange) consistently average just below 10 ppb or 20% of total ozone, and at a nearly constant value throughout the summertime ozone season. Additional time series plots for each of the monitoring sites in Tables 4 and 5 are provided in Appendix C.

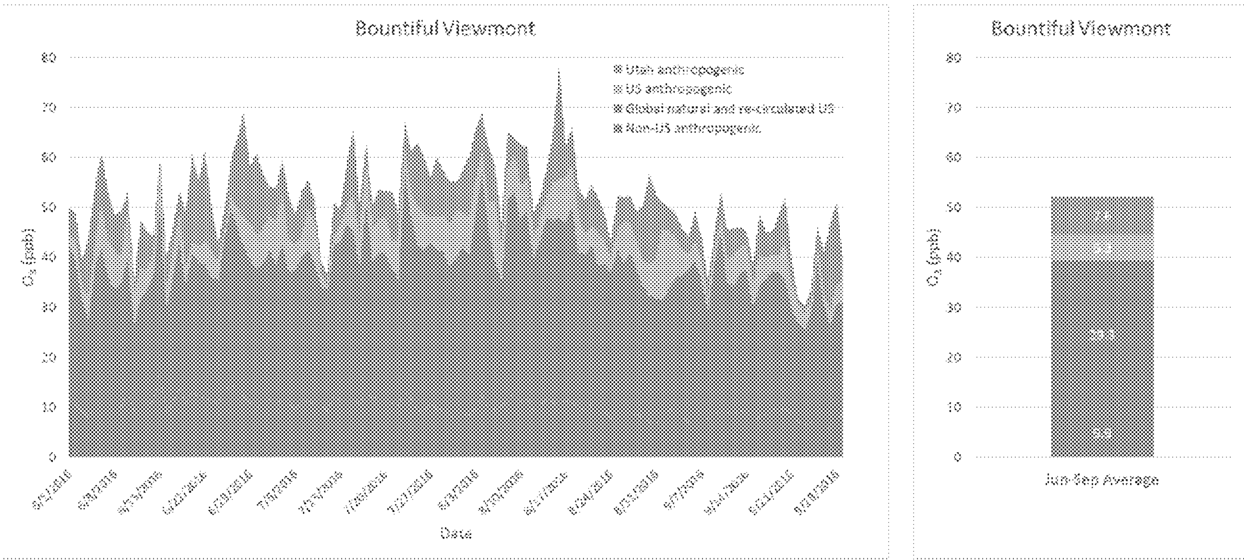

Figure 8. Time series of MDA8 ozone source apportionment results over June-September 2016 at the Bountiful Viewmont monitoring site (left), and summer-average contributions (right). The IAE contribution is shown at the bottom in orange, and all colored contributions sum to the total ozone at the top of each graph.

5.0 CONCLUSION

This preliminary modeling exercise suggests that Section 179B provisions are applicable for the Wasatch Front Ozone Nonattainment Areas. Results from two different models and techniques show that the Wasatch Front would attain the 70 ppb ozone standard but for international anthropogenic contributions.

The current highest DV for the area is 77 ppb, or 6.1 ppb above the 70.9 ppb concentration necessary to attain (by rule the decimal is truncated to 70 ppb). According to the DV scaling technique, modeled international contributions of 8.7 to 12.7 ppb are much greater than the 6.1 ppb exceedance at the most limiting monitoring site. Source apportionment results show that the modeled summer-average international contribution at the highest DV site is nearly 10 ppb and is nearly constant throughout the summertime ozone season. Furthermore, these model results are consistent with results previously reported by EPA (2015, 2019) for the same area.

Regarding model agreement with 2016 MDA8 ozone measurements at the Wasatch Front monitors, both CMAQ and CAMx generally performed adequately well and within statistical benchmarks. This means that both models exhibited a level of agreement with measurements that has typically been achieved for US regulatory modeling. Model performance degraded on days when observed MDA8 exceeded 60 ppb, with more consistent underprediction bias. Evidence presented here points to a higher likelihood that the bias on high ozone days resulted from a lack of local ozone production in both models. Furthermore, that evidence indicates that both models simulated background and US regional ozone levels rather well at rural, high-altitude monitoring sites throughout the intermountain west.

As we demonstrate in Section 3, underestimates of local ozone production may have led to overestimates of IAE contribution in the DV scaling methodology. From our analysis we expect the related error is likely less than 2 ppb, which does not change the overall conclusion that the Wasatch Front would attain the 70 ppb ozone standard but for international anthropogenic contributions.

5.1 Next Steps

A more rigorous State-led modeling analysis employing higher resolution and area-specific meteorology and emission inventories is warranted to confirm these results and to support a Section 179B demonstration. Final guidance on 179B demonstrations (EPA, 2020c) describes many analyses that could be performed, each providing specific insights into the amount, frequency and transport mechanisms associated with international contributions. Taken together, multiple lines of evidence from an array of analyses help strengthen the weight of evidence for a successful 179B demonstration.

Many of the example analyses suggested by EPA (2020c) are most applicable to primary and/or inert pollutants such as PM_{10}, and to relatively short transport paths across local international borders. However, ozone presents a unique challenge in Utah for several reasons: (1) Utah is well-removed from international borders; (2) ozone is a secondary compound formed from complex non-linear chemical interactions among NOx and VOC emissions from a multitude of sources; (3) relative to its NAAQS, ozone has a substantial global background that is derived from both natural and anthropogenic processes, including the stratosphere; and (4) as described in Section 1, ozone can persists for days to weeks in the mid to upper troposphere, which extends its source attribution to the global scale. **Therefore, photochemical models, which can address all of these processes, are**

the only tools capable of comprehensively assessing and quantifying ozone source-receptor linkages on international scales and on time scales ranging from days to seasons.

EPA's 179B guidance emphasizes the analysis of air parcel trajectories, which illustrate the historical path of air that arrived at a receptor area during a given period of time. Given the points above, it is clear that relying on simple screening methods alone (like trajectory analysis) to identify periods of global international ozone transport is problematic and insufficient. No matter how long a parcel or airmass persists over a local area, there is always a substantial fraction of air containing ozone that originated elsewhere around the globe. From another perspective, with enough time, all air parcel trajectories extending backward had, at some point, passed over other parts of the world. This is an issue that is fairly unique to ozone relative to other criteria pollutants such as SOx, NOx and PM.

Trajectory models are limited in their ability to properly address all facets of moving and churning air because:

1) Air "parcels" are treated as singular infinitesimal points that are moved according to a modeled grid of winds with, at minimum, ~10 km resolution spanning a portion of the North American continent (global wind fields are available at much coarser resolution);

2) Coarse grid spacing cannot resolve local-scale three-dimension circulations induced by complex terrain;

3) The important effects of wind shear and the resulting dispersion of an air parcel cannot be treated as singular points because the parcels have no spatial dimensions defining a volume subject to deformation;

4) The important effects of sub-grid turbulent mixing or "diffusion" are not included; these are critical processes that vertically exchange air between the surface and 1-4 km aloft during the daytime, thus providing a continuous upward ventilation of local emissions and a drawing down of pollutants from the mid-troposphere.

Point (4) merits special consideration. Without the capacity to include vertical mixing, trajectory models ignore an important and rather dynamic vertical transport/exchange process. This is particularly relevant during multi-day stagnation periods when simulated point trajectories exhibit only restricted, localized patterns of movement by the resolved wind field. The effects of shears and mixing can be somewhat addressed by tracking multitudes of point parcels initialized throughout a broad three-dimensional volume that extends over the entire air basin horizontally and through 3-4 km vertically. Then the assessment of trajectories should include the entire resulting "cloud" of trajectory paths extending up to a week in time from their initialization point.

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APPENDIX A: TIME SERIES OF MDA8 OZONE FROM CMAQ AND CAMX BETA MP

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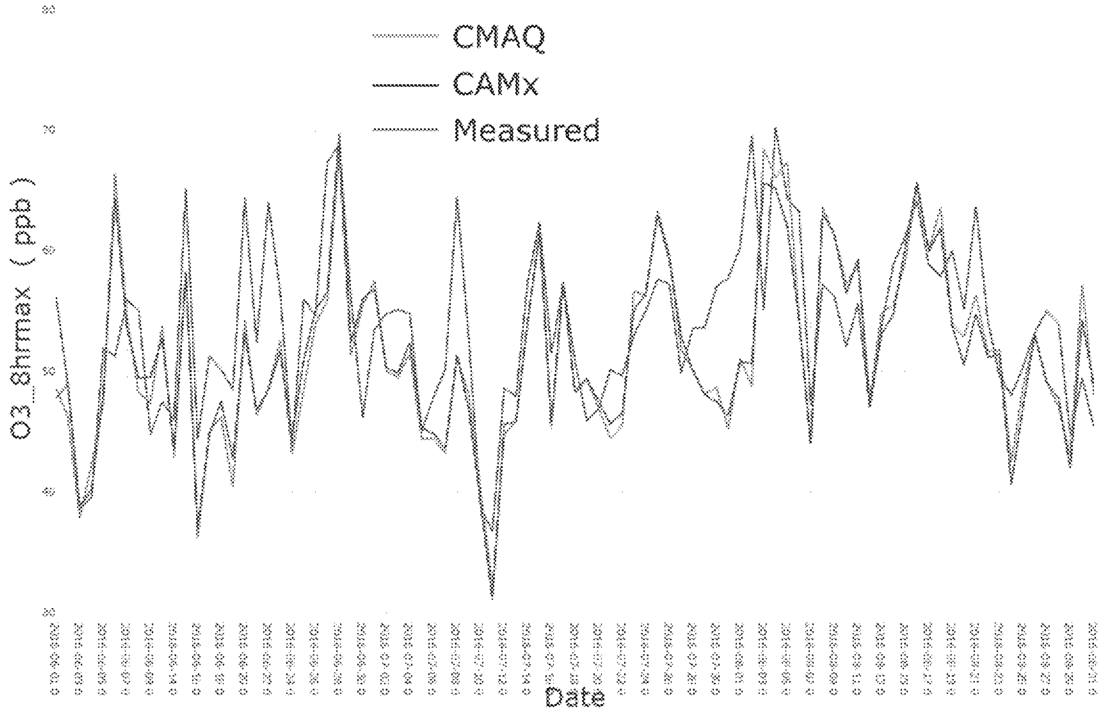

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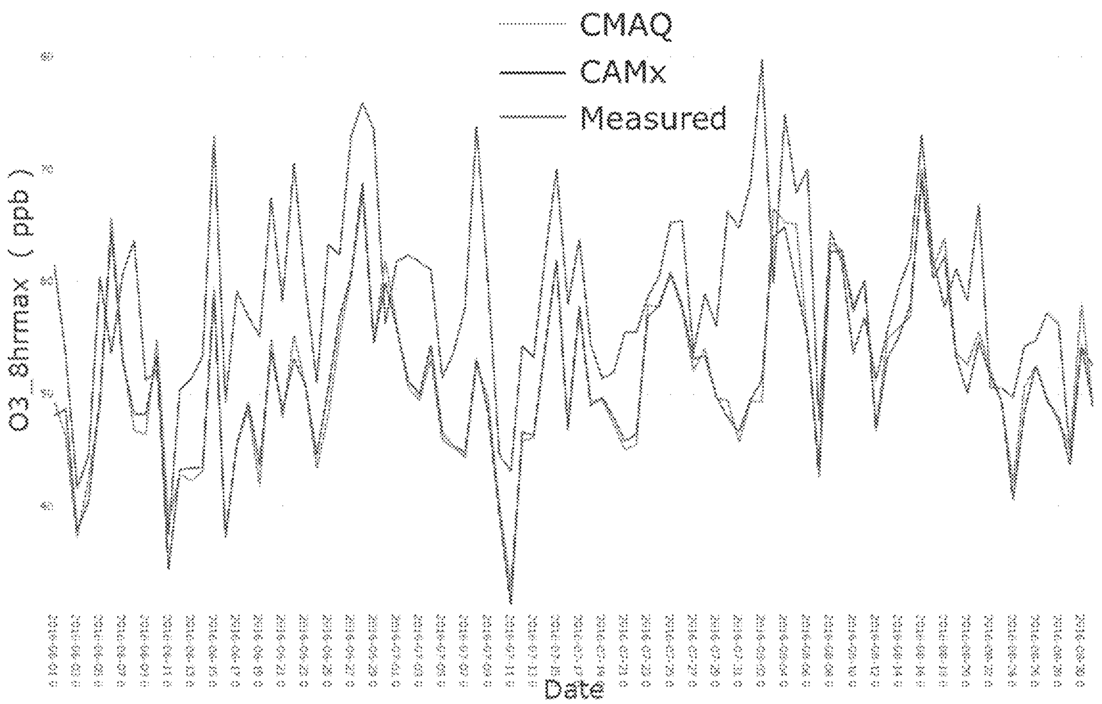

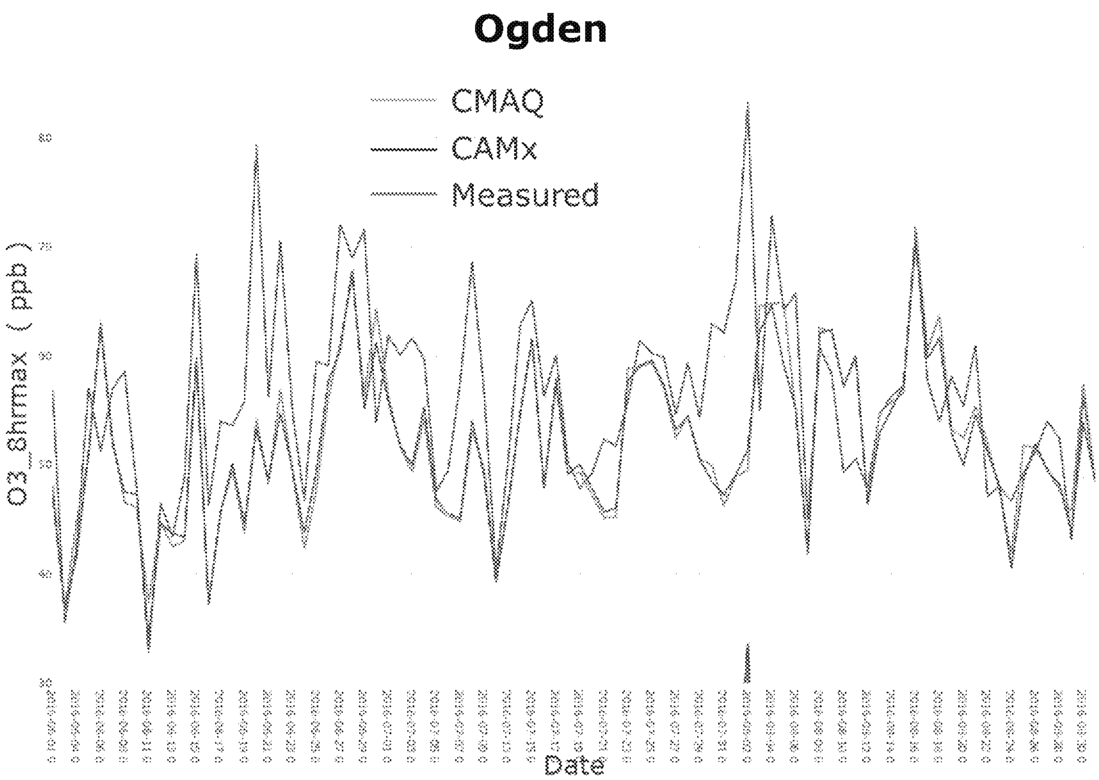
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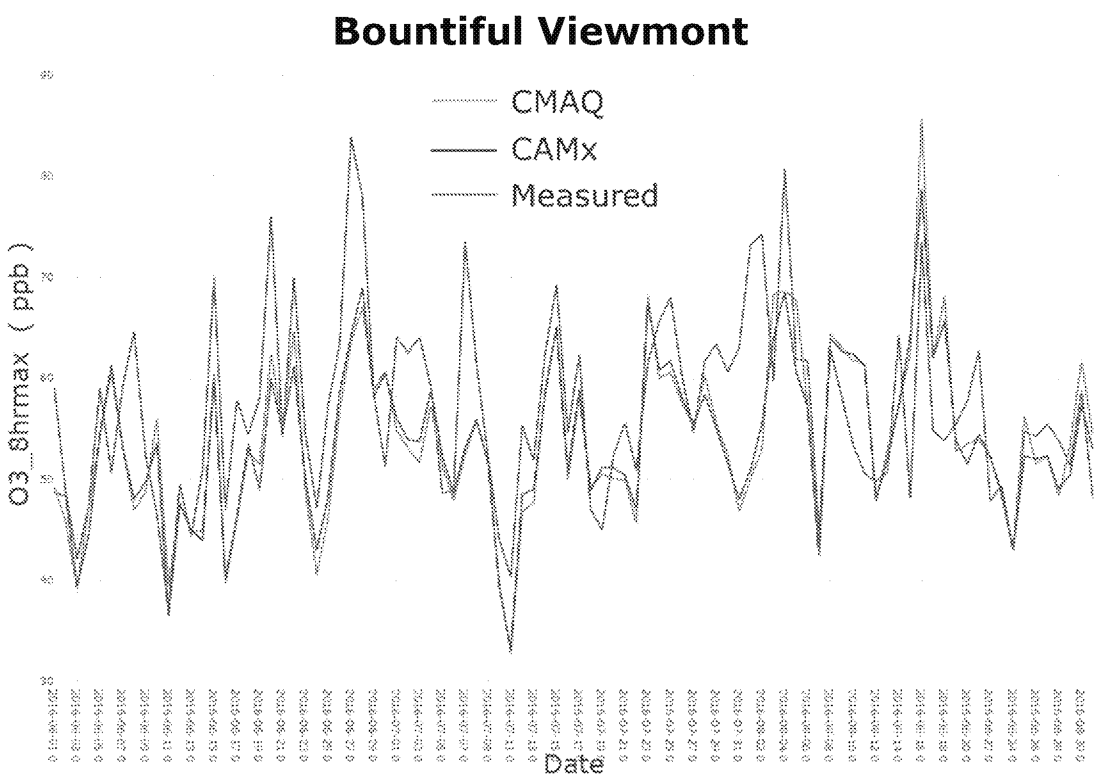
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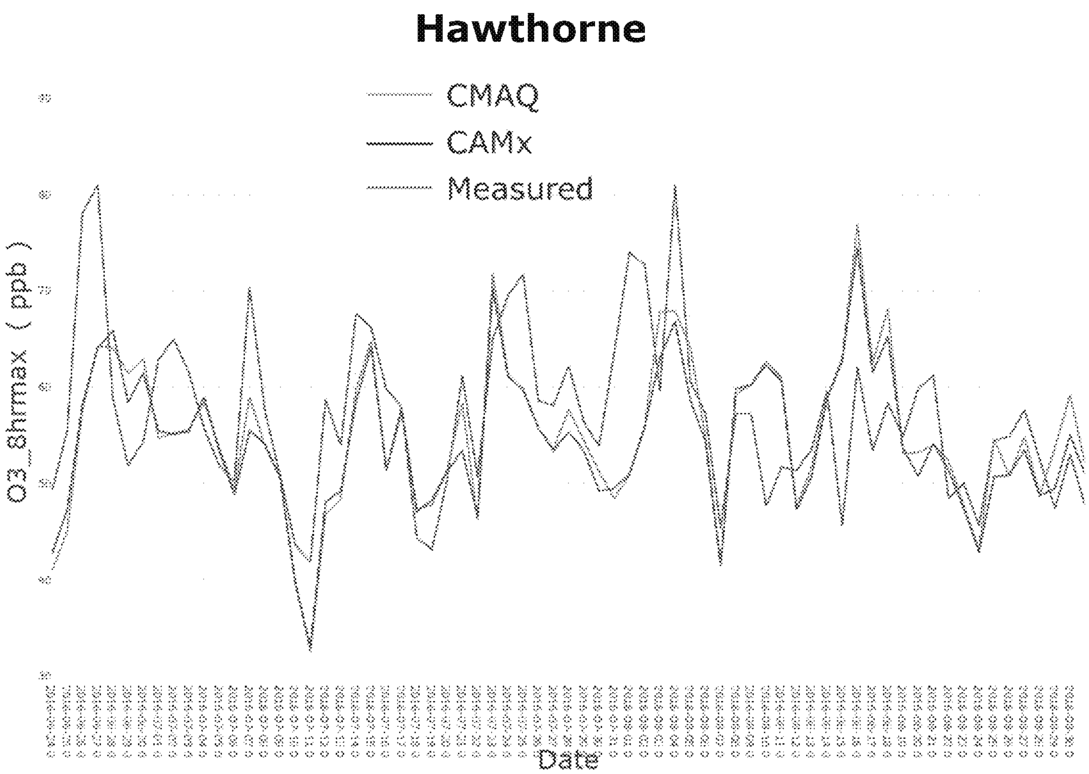
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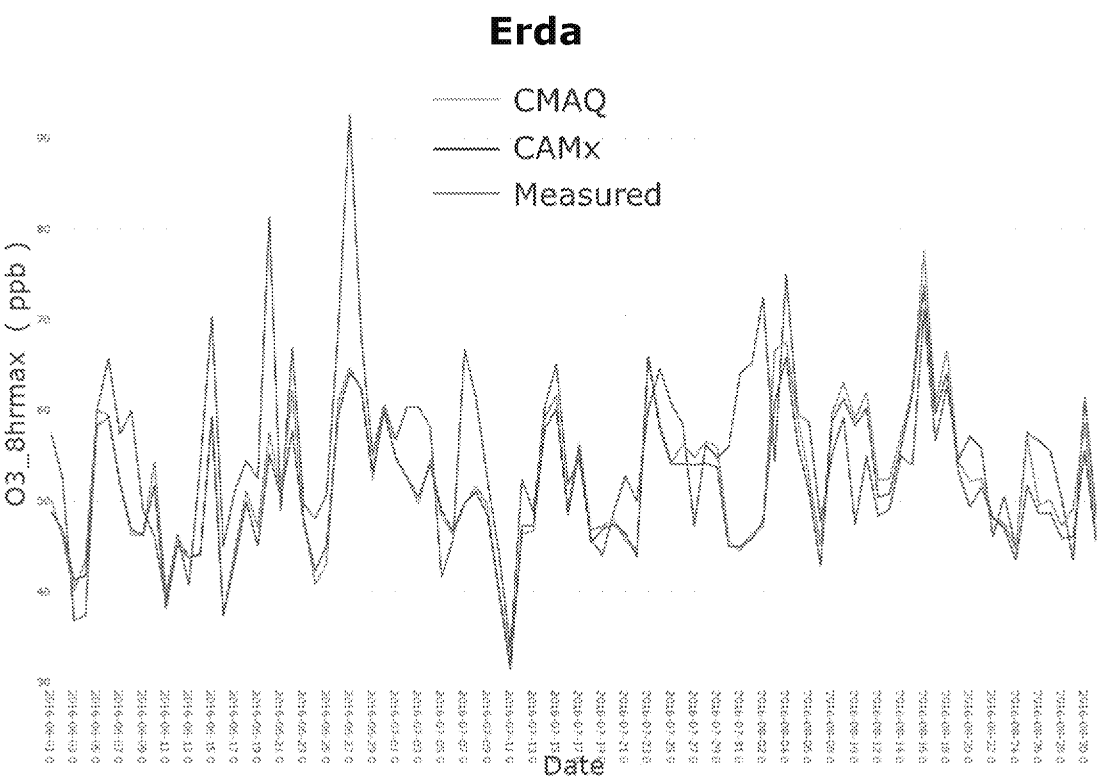
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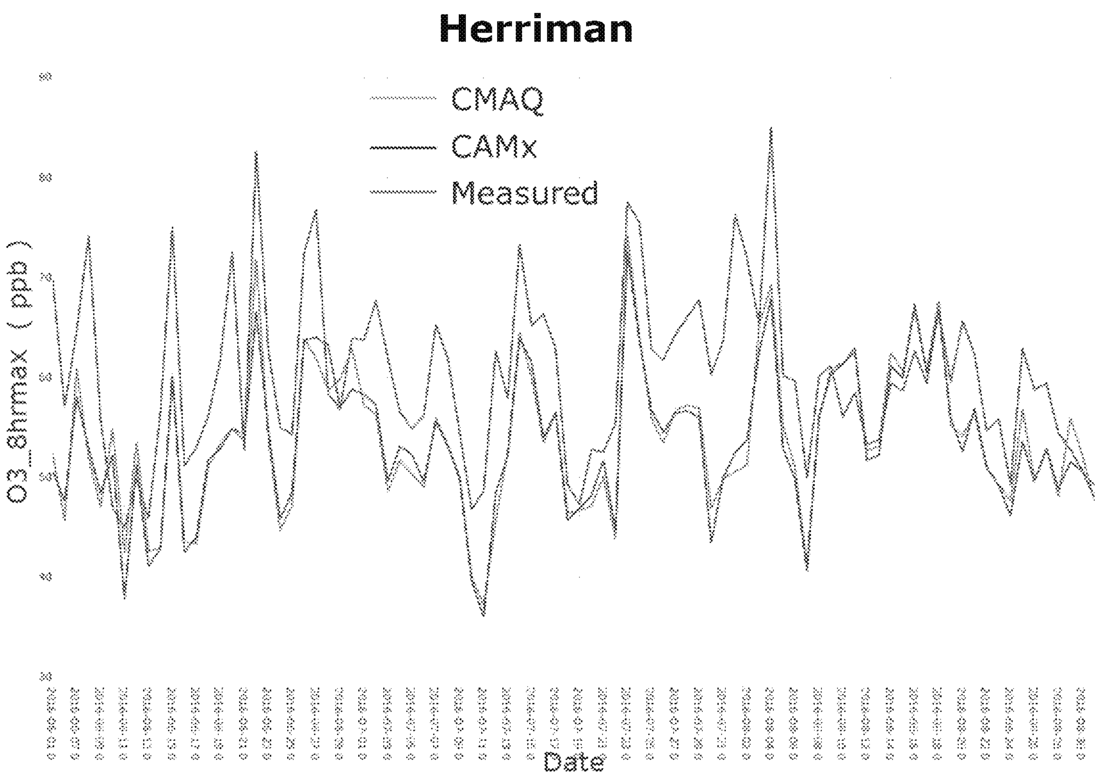
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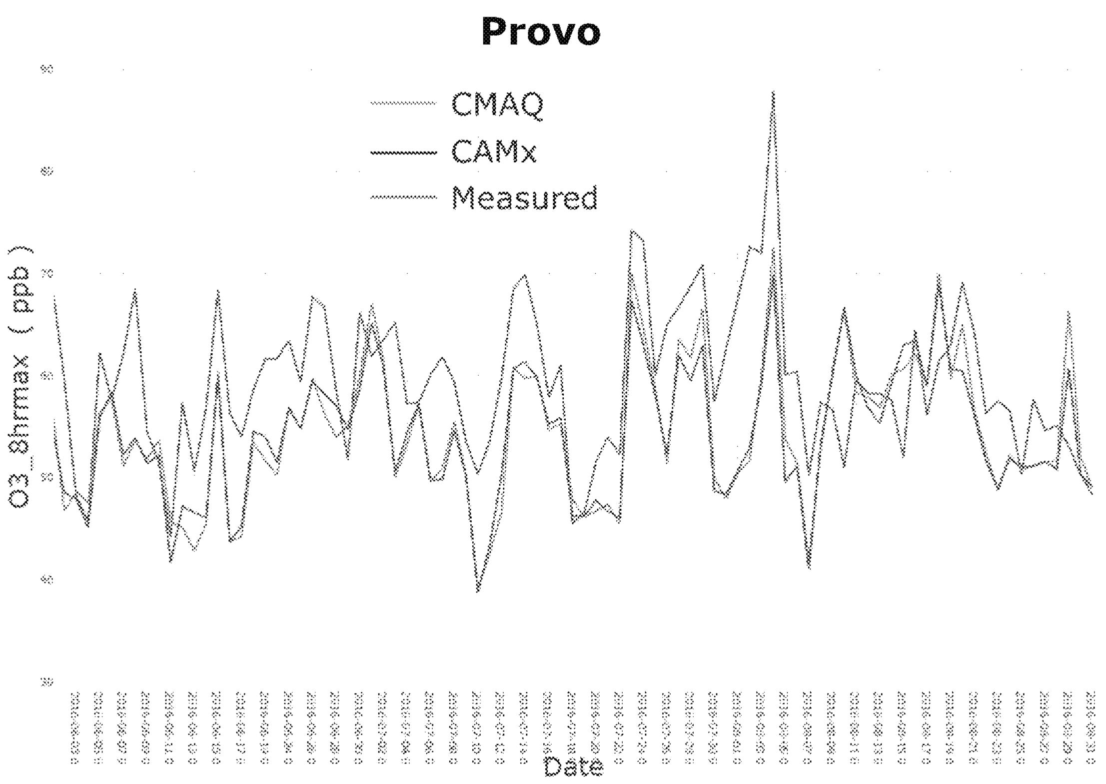
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CAMx
Measured
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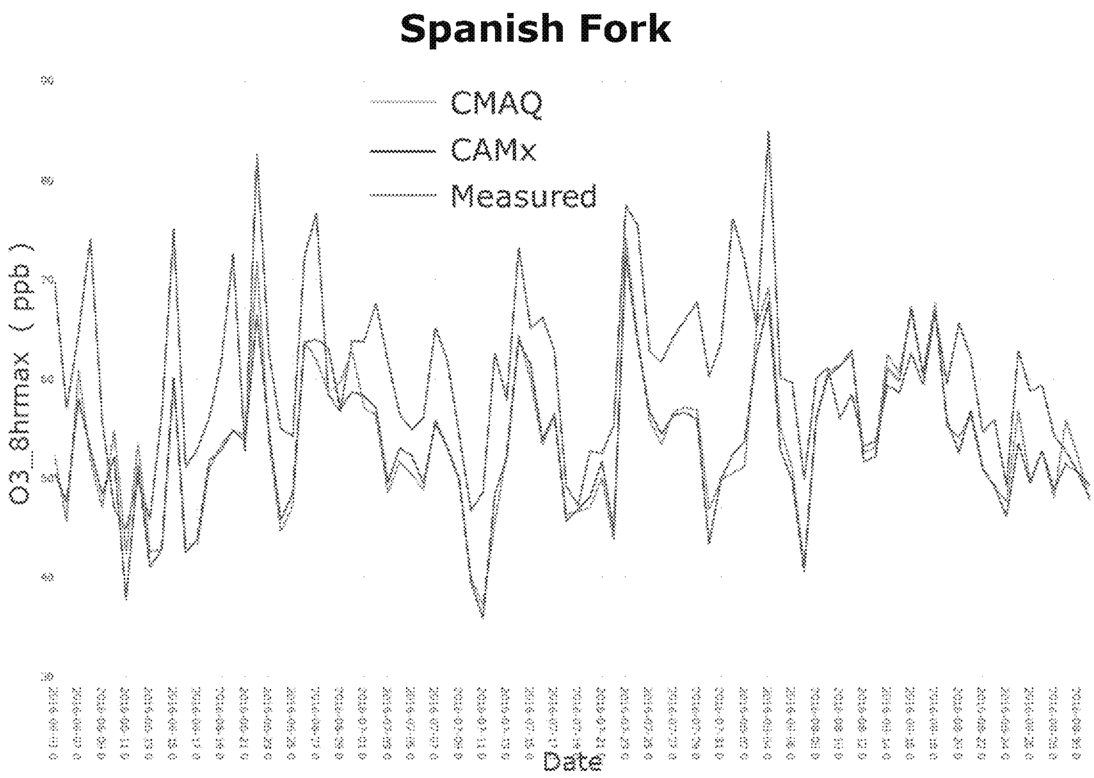
Date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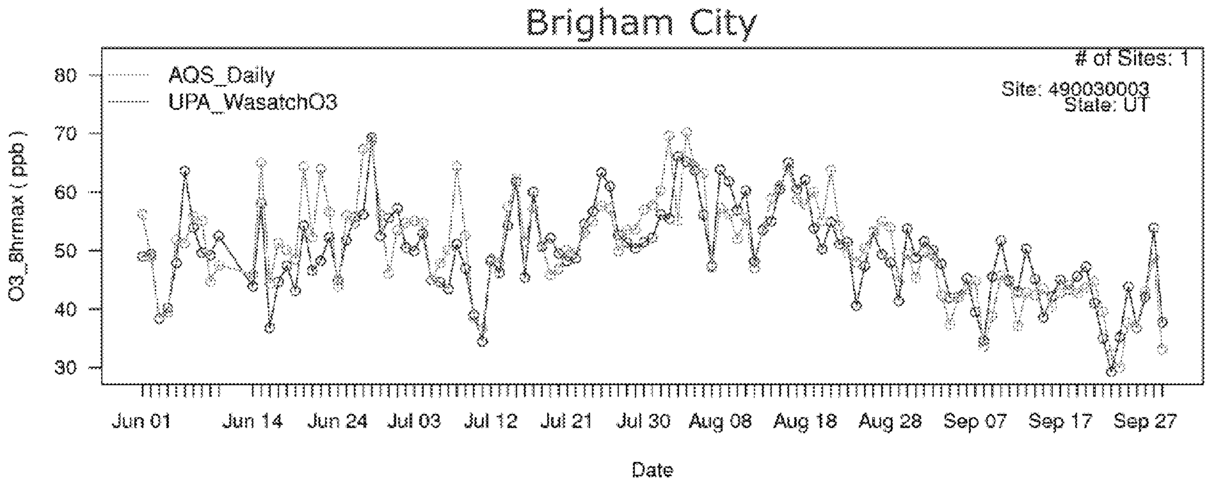
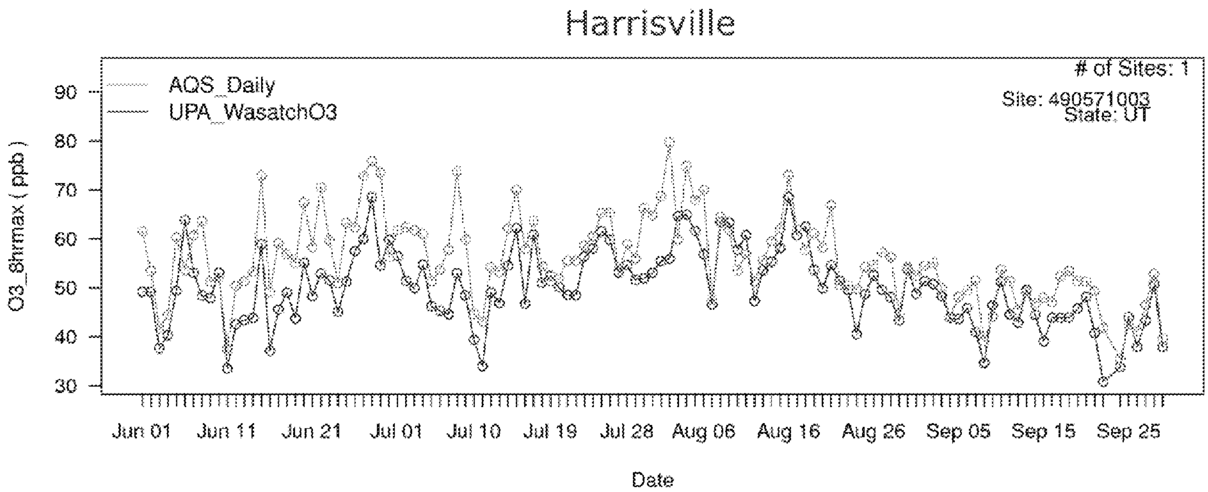
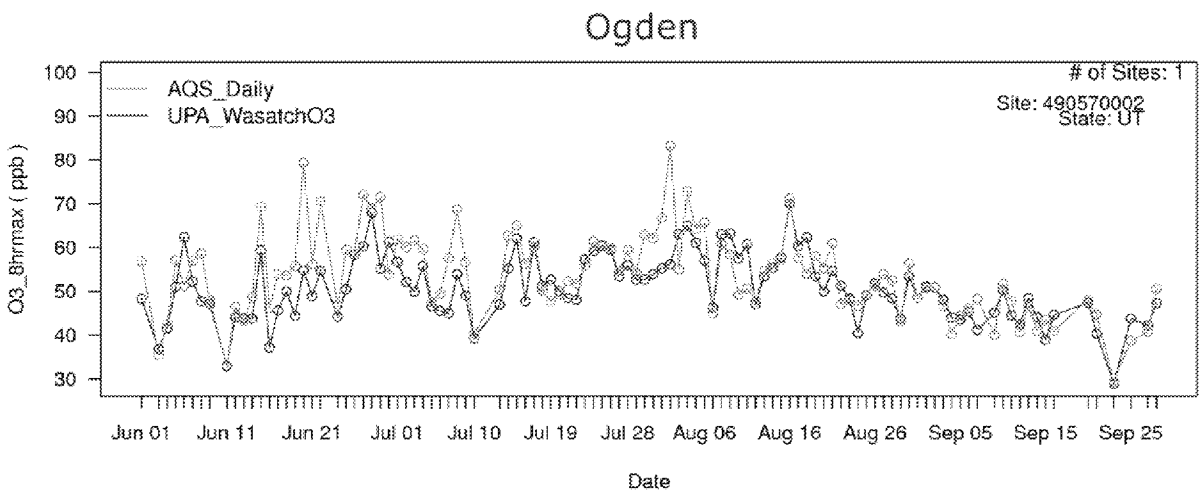
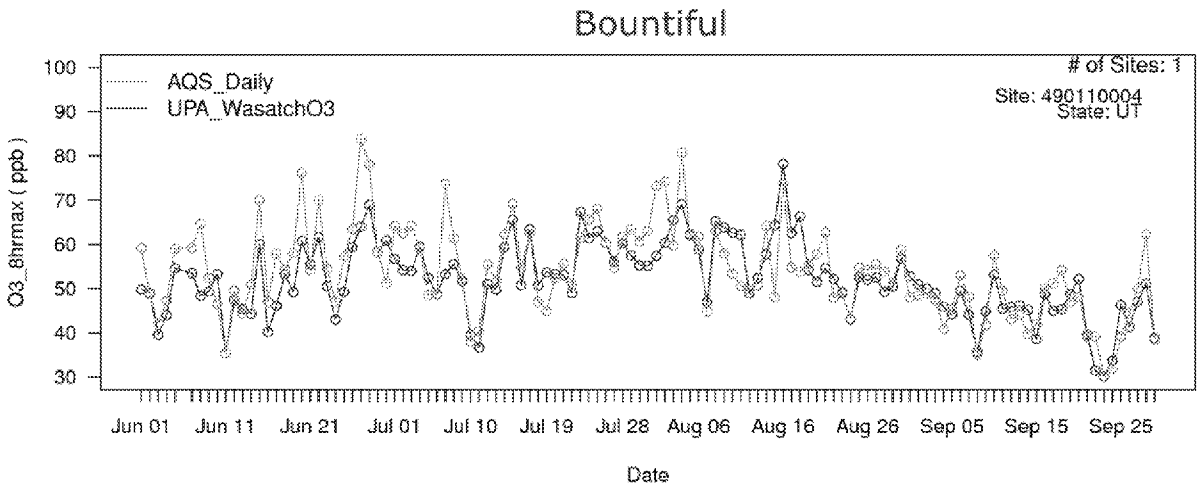
APPENDIX B: TIME SERIES OF MDA8 OZONE FROM CAMX V1 MP





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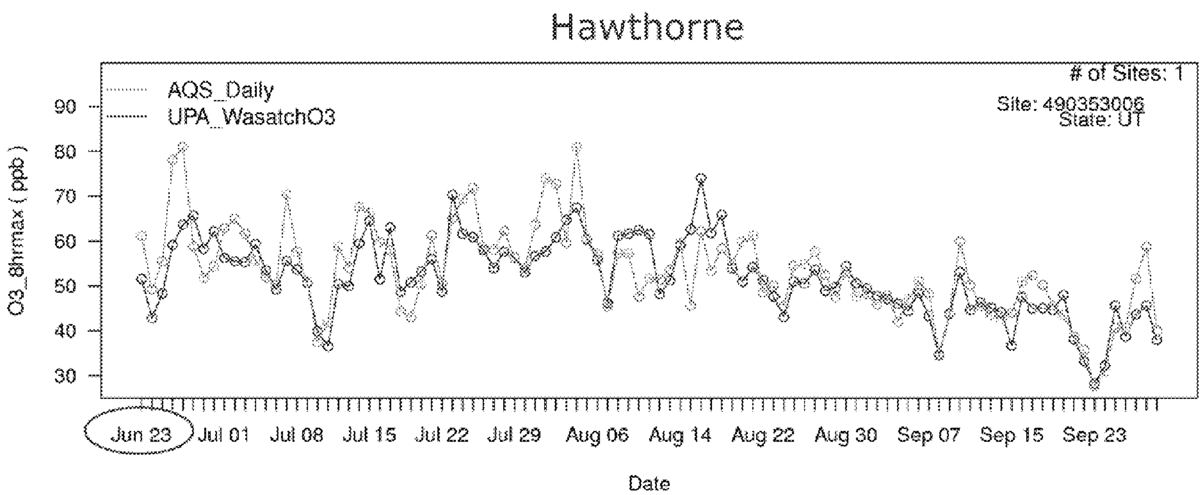
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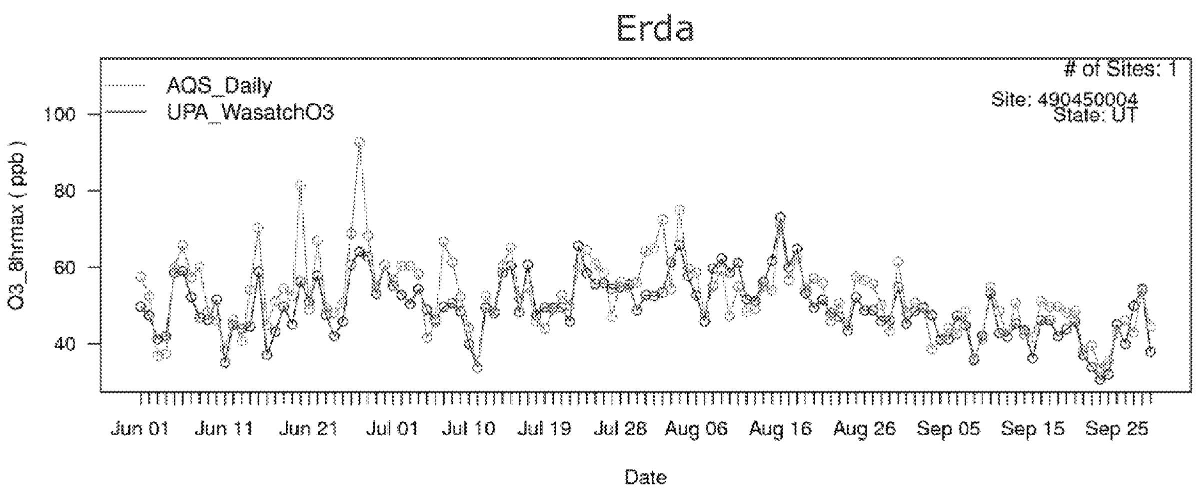
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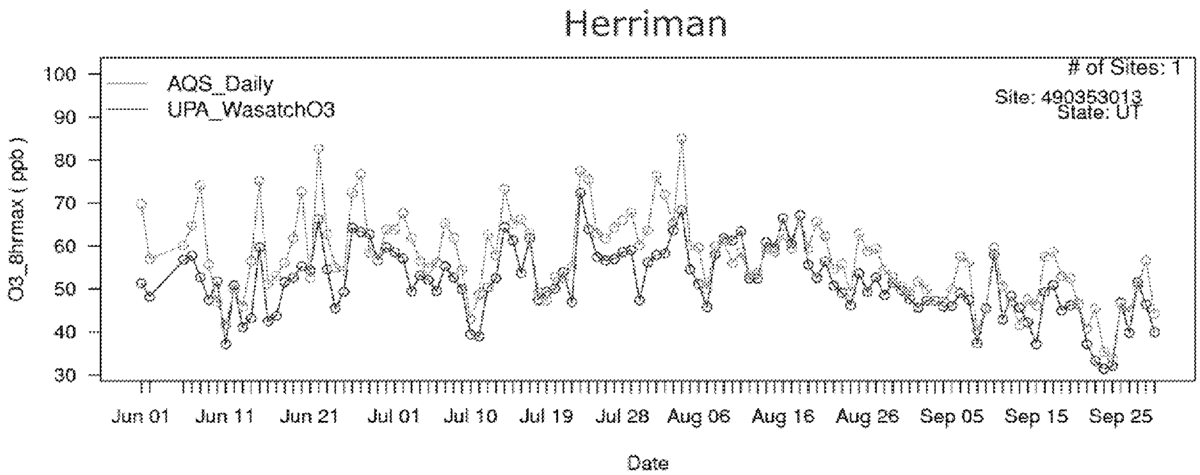
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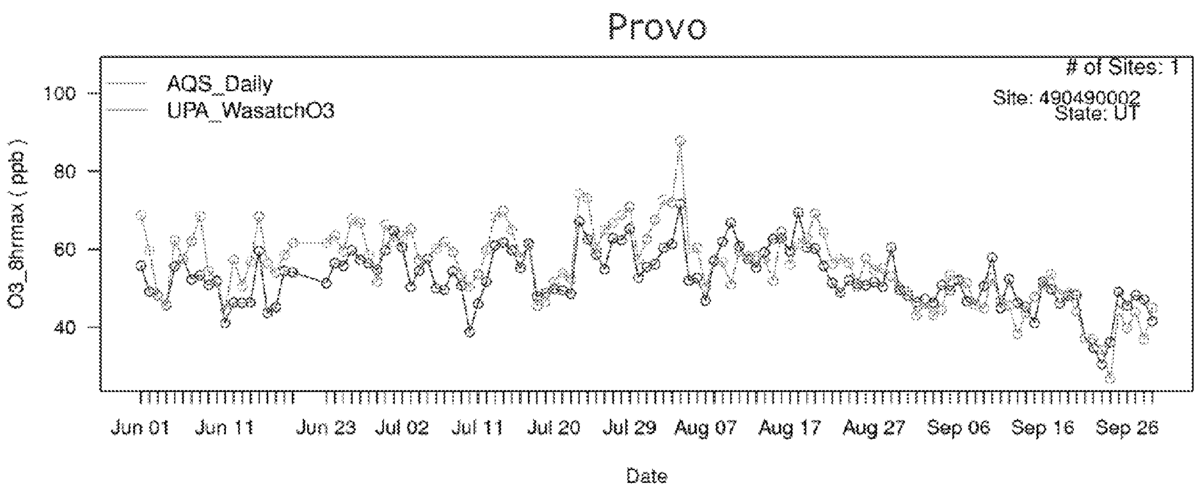
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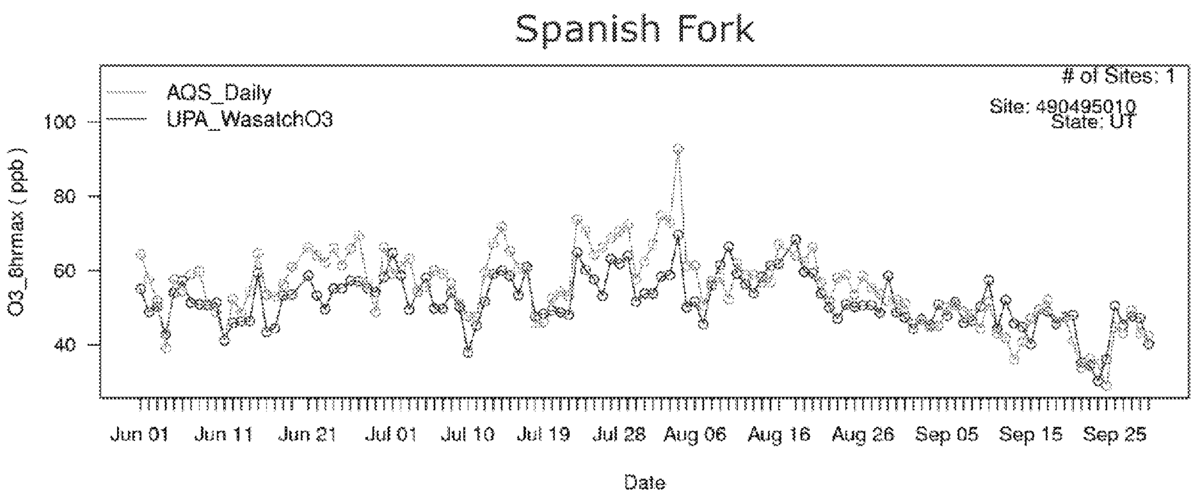
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80
60
40
Jun 01
Jun 11
Jun 21
Jul 01
Jul 10
Jul 19
Jul 28
Aug 06
Aug 16
Aug 26
Sep 05
Sep 15
Sep 25
Date

APPENDIX C: SMAT DV SCALING USING EPA BETA CMAQ BASE AND ZROW OUTPUT

Site	County	2013-2017 Average DV[1]*	Modeled RRF (ZROW/Base)	ZROW DV (≤70.9 Attains)
Northern Wasatch Front				
490110004 Bountiful	Davis	74	0.8869	66.0
490353006 Hawthorne	Salt Lake	76	0.8924	68.0
490353013 Herriman	Salt Lake	76	0.8686	66.0
490450004 Erda	Tooele	73	0.8592	62.7
490570002 Ogden	Weber	72	0.8811	63.4
490571003 Harrisville	Weber	72	0.8784	63.5
Southern Wasatch Front				
490490002 Provo	Utah	71	0.8881	63.6
490495010 Spanish Fork	Utah	72	0.8905	64.1

[1] SMAT-CE is delivered with official DV data up through 2017.
* EPA modeling guidance recommends scaling the 3-year average DV: in this case, 2013-2015, 2014-2016, 2015-2017.

Site	County	2015-2017 DV[1]	Modeled RRF (ZROW/Base)	ZROW DV (≤70.9 Attains)
Northern Wasatch Front				
490110004 Bountiful	Davis	75	0.8869	66.5
490353006 Hawthorne	Salt Lake	78	0.8924	69.6
490353013 Herriman	Salt Lake	76	0.8686	66.0
490450004 Erda	Tooele	73	0.8592	62.7
490570002 Ogden	Weber	73	0.8811	64.3
490571003 Harrisville	Weber	73	0.8784	64.1
Southern Wasatch Front				
490490002 Provo	Utah	72	0.8881	63.9
490495010 Spanish Fork	Utah	71	0.8905	63.2

[1] SMAT-CE is delivered with official DV data up through 2017.

Site	County	2016-2018 DV[1]	Modeled RRF (ZROW/Base)	ZROW DV (≤70.9 Attains)
Northern Wasatch Front				
490110004 Bountiful	Davis	78	0.8869	69.2
490353006 Hawthorne	Salt Lake	76	0.8924	67.8
490353013 Herriman	Salt Lake	77	0.8686	66.9
490450004 Erda	Tooele	74	0.8592	63.6
490570002 Ogden	Weber	75	0.8811	66.1
490571003 Harrisville	Weber	74	0.8784	65.0
Southern Wasatch Front				
490490002 Provo	Utah	N/A	0.8881	N/A
490495010 Spanish Fork	Utah	72	0.8905	64.1

[1] Using EPA-official 2016-2018 DV obtained outside of SMAT-CE.

APPENDIX D: SMAT DV SCALING USING V1 CAMX OSAT OUTPUT

Site	County	2013-2017 Average DV[1]*	Modeled RRF	OSAT DV (≤70.9 Attains)
Northern Wasatch Front				
490110004 Bountiful	Davis	74	0.8346	62.1
490353006 Hawthorne	Salt Lake	76	0.8293	63.2
490353013 Herriman	Salt Lake	76	0.8224	62.5
490450004 Erda	Tooele	73	0.8375	61.1
490570002 Ogden	Weber	72	0.8297	59.7
490571003 Harrisville	Weber	72	0.8432	60.9
Southern Wasatch Front				
490490002 Provo	Utah	71	0.8326	59.6
490495010 Spanish Fork	Utah	72	0.8330	59.9

[1] SMAT-CE is delivered with official DV data up through 2017.
* EPA modeling guidance recommends scaling the 3-year average DV: in this case, 2013-2015, 2014-2016, 2015-2017.

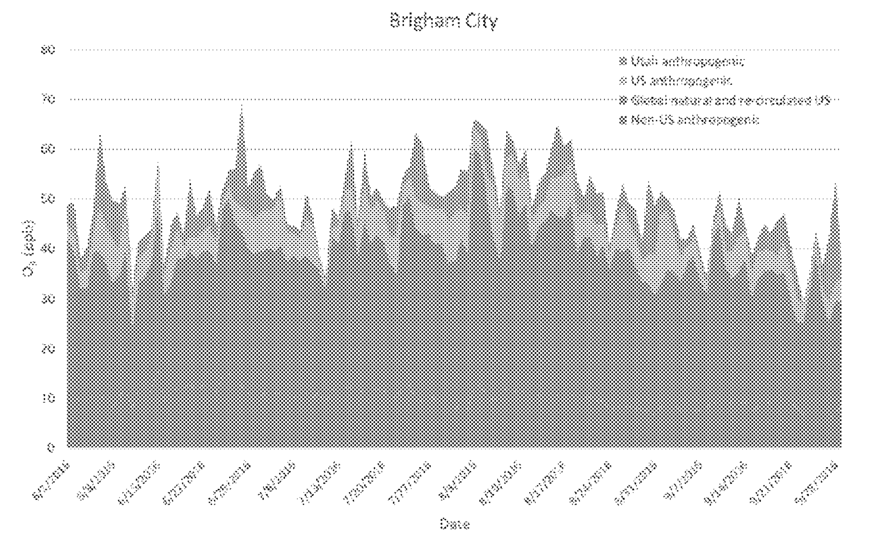
Site	County	2015-2017 DV[1]	Modeled RRF	OSAT DV (≤70.9 Attains)
Northern Wasatch Front				
490110004 Bountiful	Davis	75	0.8346	62.5
490353006 Hawthorne	Salt Lake	78	0.8293	64.6
490353013 Herriman	Salt Lake	76	0.8224	62.5
490450004 Erda	Tooele	73	0.8375	61.1
490570002 Ogden	Weber	73	0.8297	60.5
490571003 Harrisville	Weber	73	0.8432	61.5
Southern Wasatch Front				
490490002 Provo	Utah	72	0.8326	59.9
490495010 Spanish Fork	Utah	71	0.8330	59.1

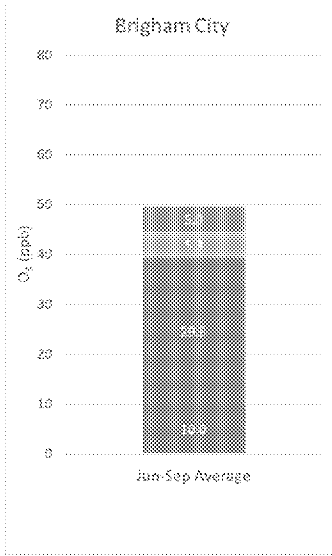
[1] SMAT-CE is delivered with official DV data up through 2017.

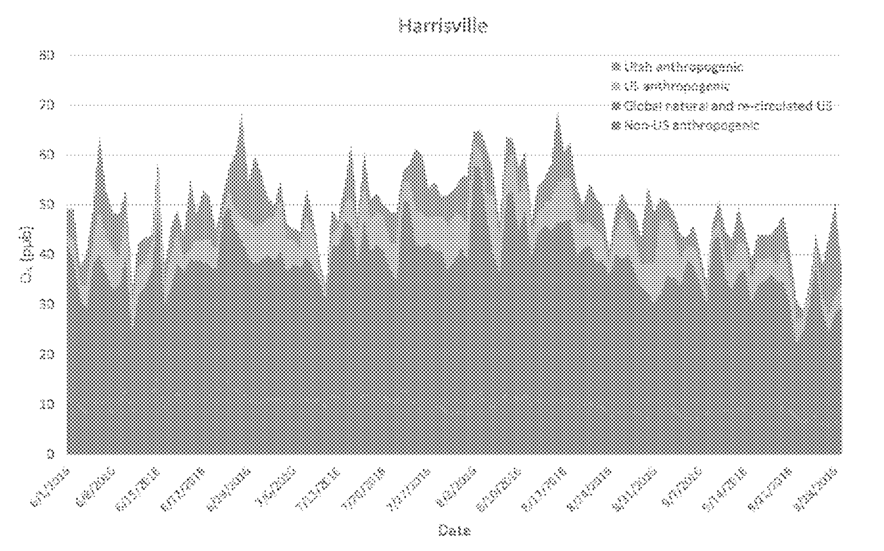
Site	County	2016-2018 DV[1]	Modeled RRF	OSAT DV (≤70.9 Attains)
Northern Wasatch Front				
490110004 Bountiful	Davis	78	0.8346	65.1
490353006 Hawthorne	Salt Lake	76	0.8293	63.0
490353013 Herriman	Salt Lake	77	0.8224	63.3
490450004 Erda	Tooele	74	0.8375	62.0
490570002 Ogden	Weber	75	0.8297	62.2
490571003 Harrisville	Weber	74	0.8432	62.4
Southern Wasatch Front				
490490002 Provo	Utah	N/A	0.8326	N/A
490495010 Spanish Fork	Utah	72	0.8330	60.0

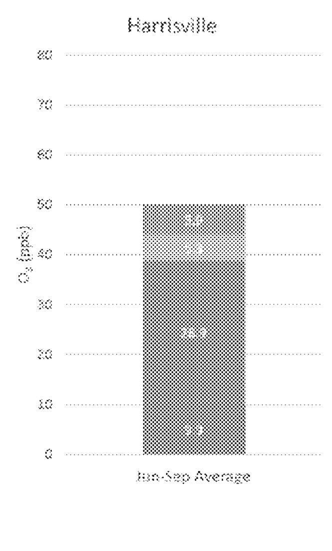
[1] Using EPA-official 2016-2018 DV obtained outside of SMAT-CE.

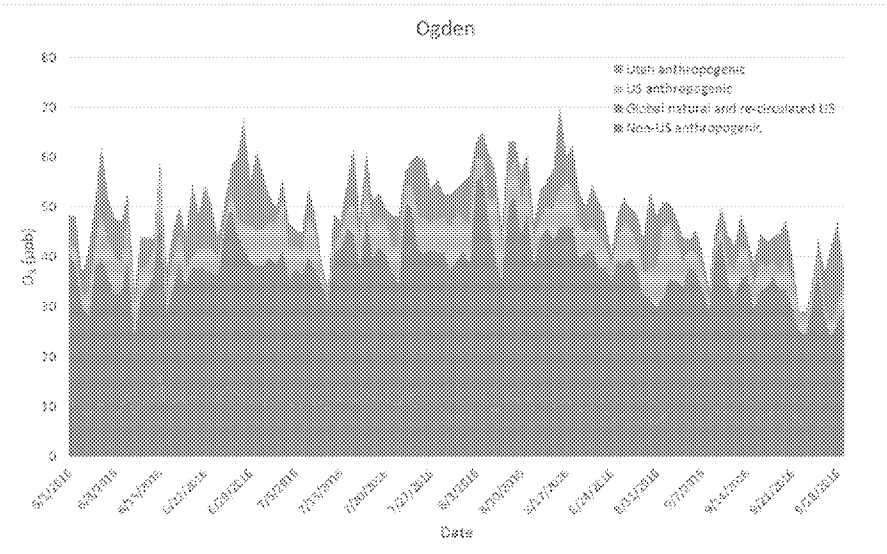
APPENDIX E: TIME SERIES AND SUMMER-AVERAGE OZONE CONTRIBUTIONS FROM OSAT

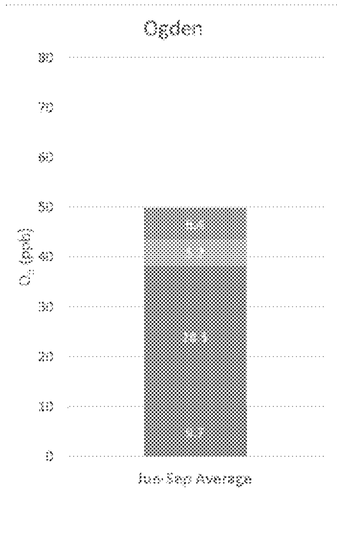


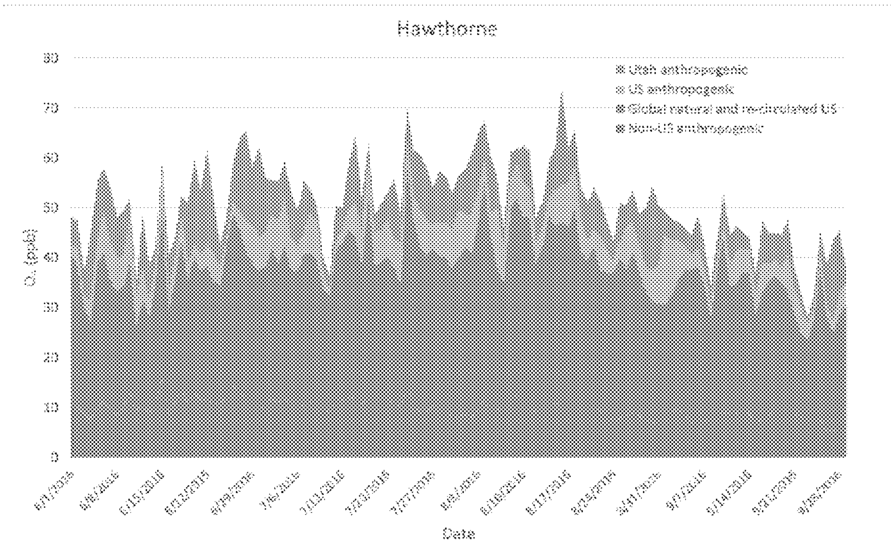


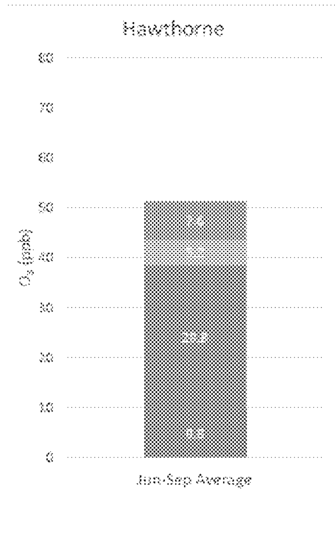


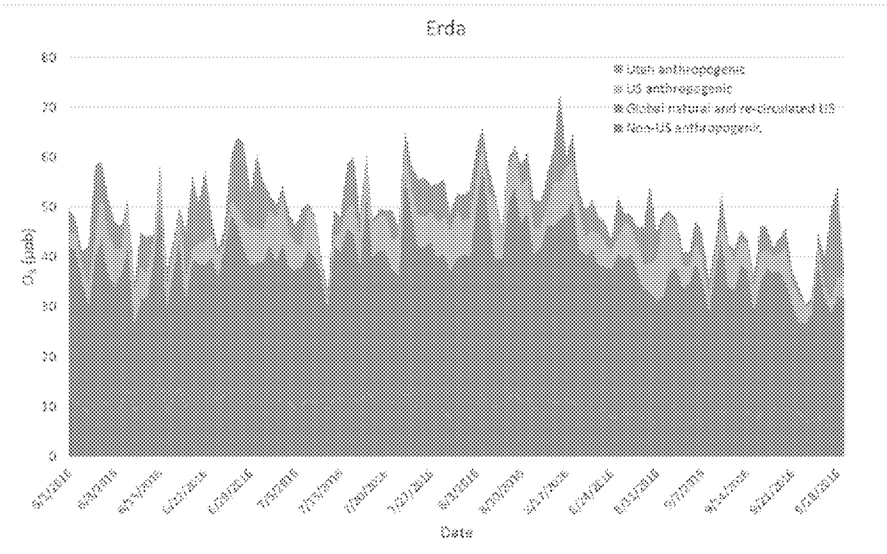


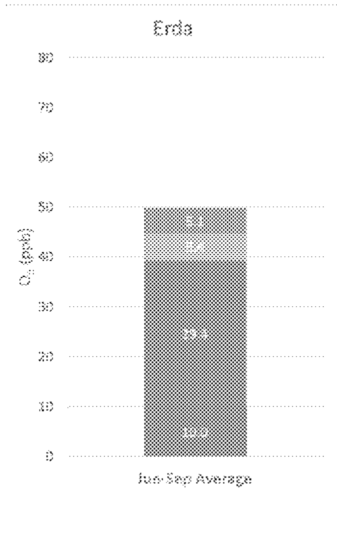

Ogden
Utah anthropogenic
US anthropogenic
Global natural and re-circulated US
Non-US anthropogenic
O_3 (ppb)
Date

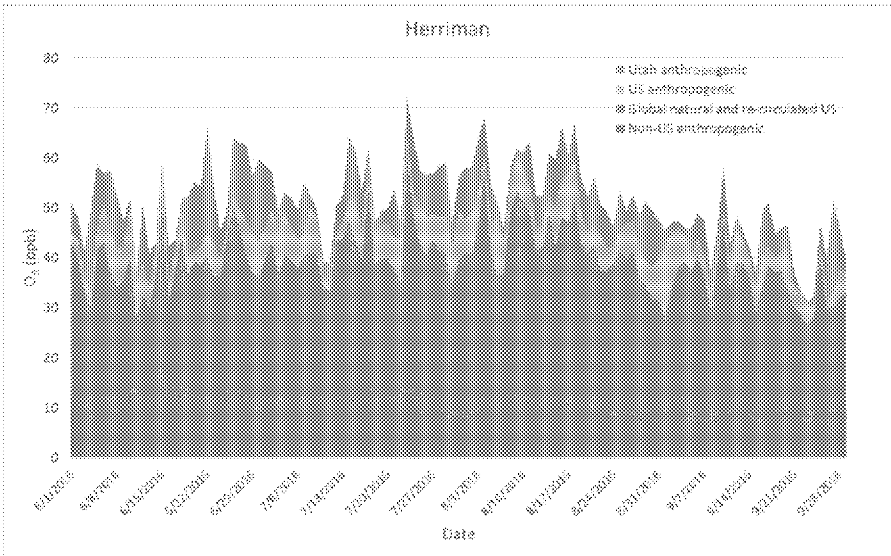

Ogden
O_3 (ppb)
Jun-Sep Average

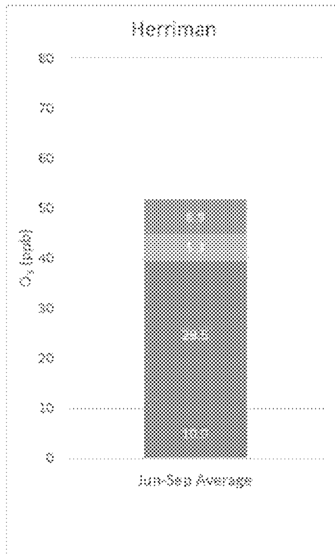

Hawthorne
Utah anthropogenic
US anthropogenic
Global natural and re-circulated US
Non-US anthropogenic
O_3 (ppb)
Date

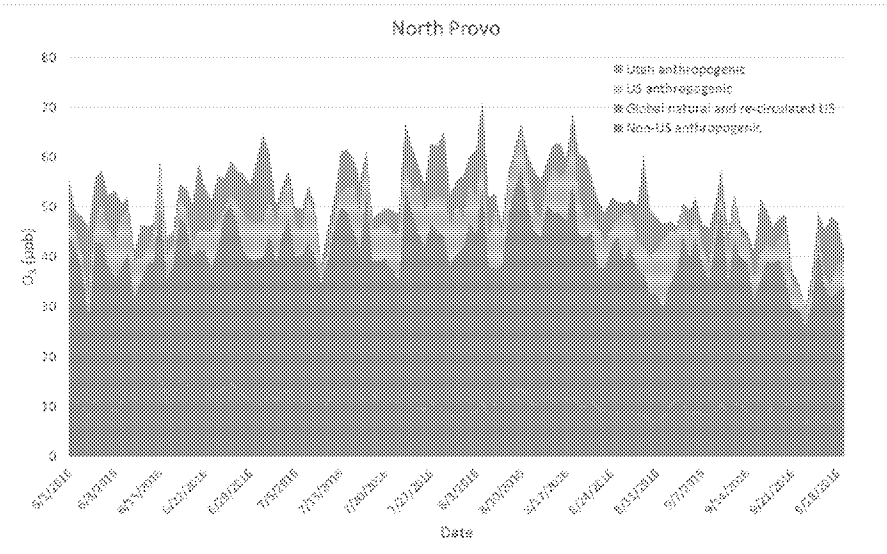

Hawthorne
O_3 (ppb)
Jun-Sep Average

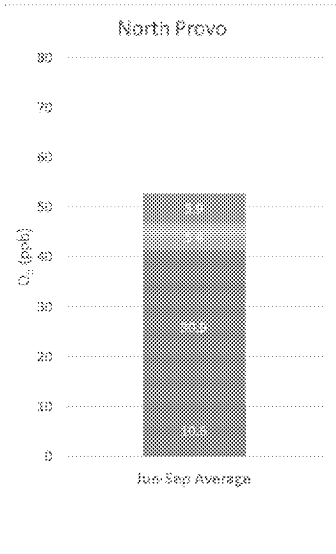

Erda
Utah anthropogenic
US anthropogenic
Global natural and re-circulated US
Non-US anthropogenic
O3 (ppb)
0
10
20
30
40
50
60
70
80
Date

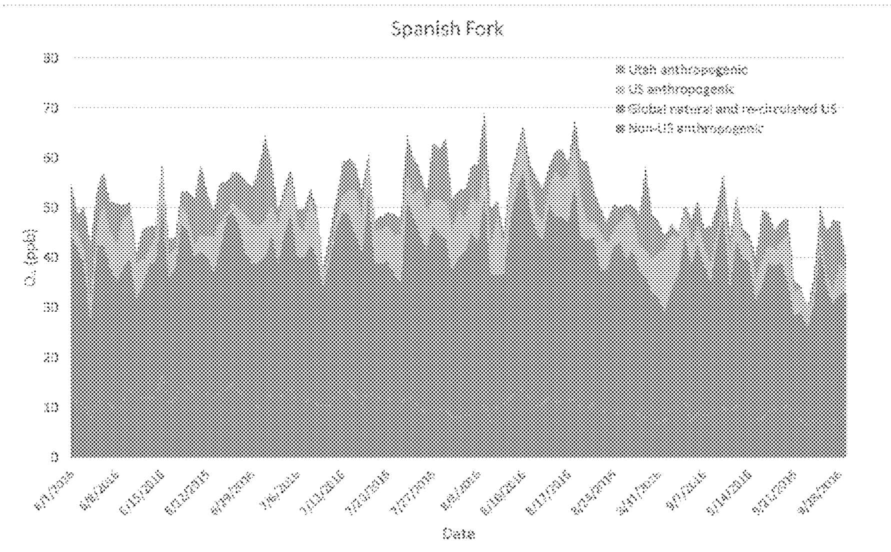

Erda
O3 (ppb)
0
10
20
30
40
50
60
70
80
Jun-Sep Average

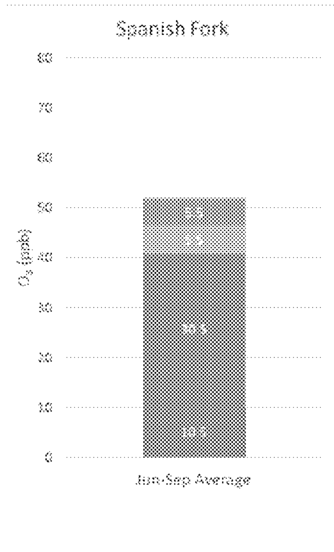

Herriman
Utah anthropogenic
US anthropogenic
Global natural and re-circulated US
Non-US anthropogenic
O3 (ppb)
0
10
20
30
40
50
60
70
80
Date


Herriman
O3 (ppb)
0
10
20
30
40
50
60
70
80
Jun-Sep Average


North Provo
Utah anthropogenic
US anthropogenic
Global natural and re-circulated US
Non-US anthropogenic
O_3 (ppb)
Date


North Provo
O_3 (ppb)
Jun-Sep Average


Spanish Fork
Utah anthropogenic
US anthropogenic
Global natural and re-circulated US
Non-US anthropogenic
O_3 (ppb)
Date


Spanish Fork
O_3 (ppb)
Jun-Sep Average